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EUROPEAN RESEARCH PROGRAM ON VISCOUS FLOWS

EUROVISC ANNUAL REPORT 1980

General Editor

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PARTIAL CONTENTS :

INTRODUCTION

This document contains the ninth Annual Report of the European Research Program on Viscous Flows (Eurovisc). It is compiled by the editors from information supplied to them by individual research workers. The aim is to assist in the coordination of research on viscous flows in Europe and to increase the awareness of workers in this field of research closely related to their own. In all some 300 items of research in nine European countries are included but inevitably the coverage within the countries cannot be considered complete. Additional relevant contributions for incorporation in future reports will be welcomed by the Editors. Wherever possible recent publications are listed at the end of each section of comments to enable more detailed information to be obtained. In all about 280 references are given. Also included are progress reports for the six Eurovisc Working Parties.

WORKING PARTIES' REPORTS

There are six Eurovisc Working parties concerned with the following subjects:

- numerical methods in fluid dynamics
- compilation of data for two-dimensional compressible turbulent boundary layers
- compressible boundary layers with heat transfer
- transition in boundary layers
- unsteady boundary layers
- three-demensional shear layers.

Progress reports of these Working Parties supplied by their respective chairmen are given below.

1 GAMM-COMMITTEE FOR NUMERICAL METHODS IN FLUID MECHANICS
Chairman - Prof. Dr-Ing N. Peters, Institut fur Allgemeine Mechanik, RWTH Aachen

The third GAMM-Conference on Numerical Methods in Fluid Mechanics was held at the DFVLR in Cologne, 10-12 October 1979, and was organised by Dr Hirschel. There were 95 participants from 15 countries. The 34 contributions treated problems of aerodynamics, meteorology, nuclear engineering and energy research. The proceedings are published in a series 'Notes on Numerical Fluid Mechanics' by Vieweg-Verlag.

A GAMM-Workshop entitled 'Numerical Methods for the Computation of Inviscid Transonic Flows with Shock Waves' was held 18-19 September 1979 in Stockholm, and was organised by Dr Rizzi and Dr Viviand. The proceedings will appear in the fall of 1980 in 'Notes on Numerical Fluid Mechanics'.

The IV GAMM-Conference on Numerical Methods in Fluid Mechanics will take place in Paris from 7-9 October 1981. The local chairman will be Dr Viviand.

2 COMPILATION OF DATA FOR TWO-DIMENSIONAL COMPRESSIBLE TURBULENT BOUNDARY LAYERS
Chairman - Prof Dr H. Fernholz, TU Berlin

The original data catalogue was published and distributed in book- and microfiche form as AGARDograph 223 in 1977. The magnetic tape data store was distributed in 1978.

The second volume 'A critical commentary on mean flow data for two-dimensional compressible turbulent boundary layers', AGARDograph 253 was published in July 1980.

A further and final contract from AGARD has now been given to Dr P.J. Finley (Imperial College London) to prepare a supplementary data compilation which will contain data published or received by the editors, too late for inclusion in the initial volume, and a chapter on turbulenece measurements in compressible boundary layers. This work is in progress both in London and Berlin, supported by a grant from DFG to H.H. Fernholz.

3 COMPRESSIBLE TURBULENT BOUNDARY LAYERS WITH HEAT TRANSFER
Chairman - Prof A.D. Young, Queen Mary College, London

The Working Party held its tenth meeting in Cambridge on 3 October 1979. Following progress reports from the members the future of the Working Party was discussed.

The Working Party agreed that its meetings provided a useful forum and a stimulus for further work but its area of interest was a difficult one that had not hitherto attracted as much attention in official quarters as had been hoped initially and progress had been somewhat slower than had been hoped. If official interest in this area were to remain at low key then there was a strong case for the Working Party to cease. However, it was felt that there were now growing and important developments such as the cryogenic tunnel which may well heighten official interest in this area and strengthen the need to keep the Working Party in being.

It was therefore agreed that the Working Party should continue but it was felt desirable to focus attention on a key problem in its area of interest and to formulate a few fundamental research projects aimed at the problem. The problem so defined was the effect of wall temperature on overall boundary layer characteristics and in particular skin friction. Three projects were put forward:

(a) pressure distributions on an aerofoil at transonic speeds with its surfaces heated and unheated,

(b) boundary layer-shock interaction on a flat plate for various surface temperatures,

(c) an axi-symmetric body with a direct frictional force balance in the form of a ring element. These friction measurements should be combined with Preston tube measurements as well as total temperature traverses in the boundary layer to provide independent skin friction results for comparison with each other. The measurements should cover a range of surface temperatures.

It was agreed that members of the Working Party should carefully consider these projects and if possible select one or more of them for investigation. It was also hoped that publicity given to them in the Eurovisc Annual Report would stimulate a wider interest in them.

The proposal was supported that consideration should be given to the next meeting being held in Paris immediately following the UITAM meeting on unsteady turbulent shear flows scheduled for the Spring of 1981 in Toulouse. It was hoped that a number of people attending the UITAM meeting would find it relatively easy to attend the Working Party meeting in Paris if there was no large gap in time between them.

4 TRANSITION IN BOUNDARY LAYERS

Chairman - K.G. Winter, RAE, Bedford

The Working Party held a meeting at DFVLR-Koln on 19 October 1979 to discuss its future role. It was concluded that it would be inappropriate to attempt to formulate a programme within the GARTEUR framework (see last year's report) and that the Working Party should continue within Eurovisc. Dr Hirschel resigned as Chairman and was replaced by Mr Winter, RAE, Bedford. The proposals for collaboration in research on transition on swept wings were reviewed and the following proposals agreed.

(i) Transition on practical wing shapes

Members to initiate collection of experimental data to provide test cases for calculation methods. As a minimum, data should include wing geometry, pressure distribution and transition location.

(ii) Basic work on swept cylinders

Experimental investigation of leading-edge transition, cross-flow instability and their interaction and of the possible influence of relaminarisation. Measurements to include as much detail as possible of the mean flow and fluctuating quantities.

Insofar as transition criteria exist they should be applied to the experimental results.

(iii) Basic work on tapered wings

The aim would be to establish the applicability of results obtained on swept cylinders as criteria to be applied locally on a tapered wing. The tests should be done at zero angle of incidence to provide a symmetrical flow but tests at other than zero angle should also enable the influence of curvature of the attachment line to be explored.

(iv) Stability theory and transition criteria

(a) Application of stability calculations to experimental results in (i), (ii) and (iii) to investigate the usefulness of the 'e^n method'.

(b) Possible extension of (a) by combination with some form of turbulence modelling.

(c) Fundamental studies of the processes of breakdown to turbulence.

(v) Investigation of the occurence and influence of laminar separation bubbles near leading edges.

5 UNSTEADY TURBULENT BOUNDARY LAYERS AND SHEAR FLOWS

Chairman - J. Cousteix, ONERA-CERT, Toulouse

A report on the third meeting held in Liverpool on 18-19 April 1979 has been issued. It included all communications which were presented. The report has been distributed to the participants and to a few members of EUROVISC. A few copies are still available.

Because of overlapping with congresses on unsteady flows in Europe it was decided to postpone the fourth meeting. EUROMECH 135 on 'Unsteady separation and reversed Flow in external fluid dynamics' will be held in Marseille on 7-9 October 1980. A IUTAM Symposium on 'Unsteady Turbulent Shear Flows' will be held in Toulouse on 5-8 May 1981. No decision has been taken for the date of our next meeting.

6 THREE-DIMENSIONAL SHEAR LAYERS

Chairman - Prof T.K. Fannelǿp, University of Trondheim

A workshop on three-dimensional turbulent boundary layers on ships was arranged in Gothenburg in June this year by Dr L. Larsson. (The SSPA - ITTC Ship Boundary Layer Workshop.) Although not a formal Eurovisc meeting, the workshop was similar in scope to previous Eurovisc workshops and well attended by Eurovisc contributors. In addition there were several participants from Japan and the United States of America. The participants were requested to calculate the boundary layer development on two ships hulls and to compare the results with experimental data obtained in Case 1 by Dr Larsson (the SSPA Model 720) and in Case 2 by Dr Hoffmann (HSVA Tanker). In all 15 groups participated

with their methods but not all of these methods were new or original. The results showed fair agreement in some variables and surprisingly large differences in others, particularly near the ships' stern. A full account of this workshop will be published by Dr Larsson and coworkers in late Autumn 1980.

The report from the Eurovisc Amsterdam Workshop (September 1979) on three-dimensional boundary layers, has been delayed but is expected in early Autumn this year. This Workshop, mentioned in the Annual Report 1979, was arranged by Dr van den Berg and Dr Lindhout, and had participants from Europe and the US. The problem considered was the boundary layer flow near the wing root for a transport-type wing planform. NLR flow visulisations were available for comparison with the theoretical results. In all six methods were used and the agreement was good in general, both between the various theoretical predictions and in comparing the theory with the experimental observations. The flow region of interest included an extensive separated area and the separation line was predicted accurately by most methods.

In comparing past workshops it is perhaps surprising to find greater discrepancies between methods and between theory and experiments in Gothenburg than in Amsterdam and Stockholm (FFA 1978). At first inspection the cases involving ship boundary layers appear less complicated than viscous flows on lifting wings; the three-dimensionality is less pronounced and separation occurs, if at all, only very far downstream on the model. But this apparent simplicity is deceptive, and it is one of the major benefits of these comparison workshops that problems can be identified and discussed in detail on a common basis.

No new Eurovisc Workshops on three-dimensional shear flows are planned for 1980 or 1981 in view of the forthcoming Stanford Meeting on complex turbulent flows and a proposed IUTAM meeting on three-dimensional turbulent boundary layers. Regular Eurovisc contributors are urged to take active part in these meetings.

1 SOLUTION OF THE COMPLETE NAVIER-STOKES EQUATIONS
Editor: W. Kordulla

The number of jobs in this section increased to 29 versus 28 last year in spite of two completed jobs, Viviand (item 1.2) and Neron (item 1.29), both from ONERA, Chatillon. Only 25 publications are being reported versus 31 in 1979. No response came from Favre, IMST, Marseille (item 1.11) or from Alziary de Roquefort and Bonnet, LDF, Poitiers, (items 1.15 and 1.42). No response for the second year was received from Gampert, UEMS, Essen (item 1.37), so that this job will be deleted next year. Only publications are reported by Ackroyd, UManMF, Manchester (item 1.23, Ref 1.23a), Peyret, UPMT, Paris (items 1.31 and 1.33 , Refs 1.31a and 1.33a) and by Ha Minh and Martinez, IMF, Toulouse (item 1.35, Refs 1.35a-c). In three jobs the work is being continued, Durst, Rastogi and Schönung, (item 1.39), Rastogi and Durst (item 1.40) and Durst and Rastogi (item 1.41), UKSFB, Karlsruhe, and comments will be given next year. Two job cards were returned, reporting 'no change', v.d. Vooren, UGM, Groningen (item 1.30), and Kleinstein, UTA, Tel Aviv (item 1.36).

Frössling at Chalmers University, Göteborg (item 1.4), has carried out further investigations of the concentration distribution in a two-dimensional room. The purpose of the work is to refine the computation methods reported in preceding years. Special attention is focused on the description of the source and also on the boundary values. Krause, Schrauf and Huang from the University of Aachen (item 1.5) report that Schrauf is now investigating the problem of steady bifurcations while Huang is continuing Liu's work aiming at accelerating the convergence of the iteration process. Peube, Pécheux and Bourgartier, LDF, Poitiers (item 1.13), study the flow in the entry region between two coaxial disks (one at rest, the other rotating). Profiles have been measured using laser anemometry, and comparisons are intended with numerical predictions. Another study concerns the flow between two rotating concentric spheres with different, but constant wall temperature. The identification of several permanent and complex structures is reported as the result of an intensive experimental investigation of the flow. Booz and Fasel from the University of Stuttgart (item 1.19) report that extensive numerical investigations of Taylor-vortex flows in a wide gap between a rotating inner cylinder and a fixed outer cylinder were carried out with the numerical method based on the momentum equation for the azimuthal direction and a vorticity equation (where a fourth-order accurate fully implicit finite-difference method is being used). The numerical results show good agreement with experimental investigations. Problems dealing with the selection of wave number were treated numerically. In addition the time dependent behaviour of flows was investigated for typical cases, when the inner cylinder starts at rest and is accelerated with a certain increase of its circumferencial velocity. In his work on rotating-disc flows Ackroyd, at the University of Manchester (item 1.26), is including flow caused by stretching moving surfaces. Bellamy-Knights at the University of Manchester (item 1.27) announces the work on compressible, heat conducting, spiral flow to appear shortly in Q.J. Mech & App Maths. The work on the asymptotic solution for an incompressible unsteady

vortex is being undertaken in collaboration with L. Hatton. During the last year Zandbergen and Dijkstra, at the Twente University of Technology (item 1.32), have found the complete structure of the solution for the rotating disk problems[1.32]. As it turns out there are two distinct infinite sets of solutions. One of the families wraps itself around $s = 0$, the other one has what may be called a singular point of bifurcation for a certain value of s^2 . Hence it wraps itself around two points $s = \pm 1{:}4355$. The numerical results obtained for the higher order solution branches are characterised by the occurrence of a chain of large humps. It is possible to obtain asymptotic results for the interconnection between two of these humps. In Ref 1.32b a number of results have been given which on the one hand give much more insight in the behaviour of these solutions whereas on the other hand 'quantitative' agreement can be obtained with numerical calculations. The stationary problem seems to be solved completely, except perhaps for the determination of the limit branch of the solutions for $s = 0$. For instationary problems there is much less progress. The main interest is now the derivation of an equation which at least asymptotically gives correct boundary conditions far from the disk. Tsen and Bouriot at the University of Poitiers (item 1.18) report the simulation of the non-linear growth and energy transfer of Helmoltz instabilities in an infinite shear layer, and the simulation of the spatial growth of transversal waves in a mixing layer of tangent hyperbolic bubble.

Mitra and Fiebig at the Ruhr-University of Bochum (item 1.14) have completed works on viscous nozzle flows with vibrational and vibrational-dissociational nonequilibrium. Results have been obtained for computations of frozen nozzle flows by slender channel equations and by conventional methods of boundary layer and core flows. Results are being compared and will be reported later. The development of an implicit numerical scheme for the solution of Navier-Stokes equations in channels has been discontinued, for the time being.

Palm and Johannessen from the University of Oslo (item 1.25) continue their LDA-measurements on casts of a human arterial bifurcation for both steady and pulsating laminar flow.

Hollanders at ONERA, Chatillon (item 1.28), has restricted the hybrid implicit-explicit-method to low Reynolds number flow calculations because of the weakly dissipative nature of the implicit scheme. A more dissipative implicit scheme has been under study for one-dimensional (high Reynolds number) flows, and is now being extended to two-dimensional shock-boundary-layer interaction problems. Morice at ONERA, Chatillon (item 1.34), has tested the method, developed by Brédif under the same item, with respect to its robustness and versatility. Satisfactory results are being reported for the flow past a NACA 0018 airfoil at $Re = 5000$ and for the separated flow in a channel with an abrupt enlargement at $Re = 100$ and 191.

Lasek at CNRS, Meudon (item 1.38), reports that the flow in the neighbourhood of the stagnation point of a sphere starting from rest has been described theoretically; the description gives three different systems of equations.

In a new job Haase from Dornier (item 1.43) reports that a set of programs has been developed to predict unsteady two-dimensional flows with the Navier-Stokes equations[1.43a&b]. In order properly to simulate, at least globally, turbulent flows it is intended to combine the solution with a boundary-layer code. Concerning three-dimensional flows, the Navier-Stokes equations have been solved for Cartesian coordinates to predict laminar flow separation phenomena on prolate spheroids[1.43c-e]. This method has been improved with respect to accuracy and iteration convergence, and has been tested for a slender body at $Re = 5105$ and $\chi = 15^{o}$.

Another new job by Leschziner at the University of Karlsruhe (item 1.44) concerns the simulation of two-dimensional recirculating water flows with a free surface and a spatially as well as temporally variable bottom boundary. The code is intended for the calculation of the vertical structure of natural water flows (eg river-reservoir system) which are turbulent and buoyant and contain dissolved species as well as sediment. The code can, at present, simulate time dependent laminar flows with a free surface and variable bottom. The numerical grid used is quasi-orthogonal and consists of two matched sub-grids, one adapting to the bottom and the other to the (moving) surface. The code solves (with ADI methods) the equations of momenta and continuity in the vertical plane. The dependant variables are the velocities, the dynamic pressure and the water-surface elevation. The water surface is calculated by solving an equation representing the kinematic boundary condition for such impervious, time-dependent boundaries. Cases simulated hitherto time-dependent flows in cavities, backward-facing steps, variable-geometry diffuser, and wave-propagation phenomena in basins.

The last new job (item 1.45) is by Schönauer from the University of Karlsruhe. Schönauer reports that the SL (selfadaptive solution) program package (see ERPS S79020 in Eurovisc Annual report 1979, page 132) is applied to the solution of the two-dimension dimensional Navier-Stokes equations for (a) the flow-driven cavity, (b) the cavity with natural convection and (c) a more complicated domain with an outer circle filled with fluid and two hot and two cold circular areas inside to induce convection. Together with the solution an estimate of the discretisation error is computed by the method of the 'difference of difference quotients'. In example (a) there is a singularity in the upper corners and the solution method makes this behaviour clearly visible by larger errors in these corners if the order of the difference method is increased or the step size is decreased. In example (b) an optimum order of the difference star and optimum nonequidistant step size are automatically determined to meet a prescribed accuracy. In example 3 the program is used for an arbitrary two-dimensional domain, and together with the solution for such a complicated flow the error field is computed. Conventional difference methods with one fixed order are contained as a subset in the SL package.

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propagation is only possible along so-called energy spirals. This result supplements those of the linear stability approach and is being prepared for publication. A publication on the earlier work has now become available[2.10a].

Van de Vooren and Van Stijn, University of Groningen, have developed a new method for solving the Orr-Sommerfeld equations (item 2.29). The method is described in Ref 2.29a. The influence of non-parallelism of the flow on the stability of the Blasius flow will be investigated. They intend to investigate also the stability with regard to oblique disturbances.

The stability of Stokes boundary layers is studied by Rott and Monkewitz, Technical University of Zürich (item 2.30). The linear stability of the time-dependent velocity profiles is calculated with a two time-scale development of the Orr-Sommerfeld equation (slow scale for the velocity profile, fast scale for the disturbance).

Haaland, University of Trondheim, reports that not much could be done during the past year on his work on the stability of free convection flows (item 2.31). However, computer programs have been developed and tested, and it is hoped that the job can be finished in the near future.

Van Ingen, Technical University of Delft, reports no progress with the development of his method to predict transition (item 2.9).

There are three transition studies being carried out at CERT, Toulouse by Michel, Cousteix, Arnal and Gleyzes (item 2.12).

(i) A study of the effect of a positive pressure gradient on the transition process. The experimental part of this study has been terminated. The aim was to investigate how the initial structure of the turbulent boundary layer depends on the transition process. Large differences in the initial turbulence structure may be expected, since at zero pressure gradient the transition process is characterised by the intermittency phenomenon, while downstream of a laminar separation point simply a progressive deformation of the instability waves has been observed. On the theoretical side practical transition calculation methods have been investigated. Granville's method was found to be the mose adequate. Granville's method has been extended by taking into account the external turbulence level. The finite extent of the transition region is considered in the boundary layer calculations by introducing an intermittency factor, which is a function of θ/θ_T, where θ_T = momentum thickness at transition onset.

(ii) A study of the effect of roughness on transition. The effect of a carborundum band and a series of wires perpendicular to the leading edge were investigated experimentally. The latter method to trip the boundary layer was found to be less efficient.

(iii) A study of laminar separation bubbles. A new test set-up has been built with an enlarged airfoil nose, corresponding to a chord of 2.5 m. The airfoil is truncated at 13% chord and is provided with a blown flap. It has been proved experimentally that the velocity distributions are identical in the nose region of the truncated airfoil and the whole airfoil, if the stagnation point is at the same position. It is the intention to

perform detailed hot wire and laser measurements in the separation bubble on the airfoil nose. Calculation methods for bubbles are also being developed. Besides a field method a new inverse integral method has been developed for bubbles. Closure relations are provided by similarity solutions, extended to reverse flow cases, both laminar and turbulent. A simple intermittency function is applied in the transition region. Comparison with experimental results was very encouraging. There are three publications[2.12a-c].

The work of Maurer and Petersen, DFVLR, Köln, on transition detection with lasers (item 2.3) has produced promising results. These results have not yet been published, but there is publication of more general nature about lasers[2.3a]. Further plans are the application of lasers in cryogenic wind-tunnels.

A number of studies related to transition are being carried out at Imperial College, London, under Bradshaw (item 2.26).

(i) A study on low Reynolds number effects. This study is now completed. The experiments indicate that at low Reynolds numbers the mixing lengths tend to rise, following generally accepted trends. However, no effect of distance from transition was apparent in this low speed experiment, as contrasted with earlier results of Bushnell et al in a high speed flow. However, the small mixing lengths found in this high speed flow can be reproduced by a compressible turbulent boundary layer calculation when incorporating bulk dilatation effects. A report summarising these findings is in draft.

(ii) An investigation of turbulent spots in a boundary layer on a convex surface. Flow visualisation studies suggest that, due to the stabilising curvature, the lateral growth rate of the spots is considerably less than on flat plates. Quantitative measurements are in progress.

(iii) In connection with transition, calculations of burst development using inviscid vortex-tracking techniques have been started. Although closely related to large eddy simulation, this approach is likely to produce relatively cheaply semi-quantitative results, permitting say comparison of developments on plane and curved surfaces.

The investigations on transition in three-dimensional boundary layers by Poll, Cranfield Institute of Technology, are continuing (item 2.20). Further tests have been done on the untapered swept wing model. These tests were directed towards understanding the types of disturbance, which lead to turbulent bursts. Attempts were made to measure the skin friction using embedded hot wires. For the further investigations a highly tapered swept wing model, which is being built, will be employed. In addition an experiment is being performed in a supersonic wind tunnel, where transition by leading edge contamination is being examined on a swept circular cylinder. No results have been obtained as yet. Two new publications have become available[2.20a&b].

Shaw et al, University of Liverpool, investigate transition in the conditions occurring in turbomachines. In job 2.27 transition is studied in boundary layers on curved surfaces at various external turbulence levels, pressure gradients and flow histories. In the new job 2.32 the effect of roughness on boundary layer transition will be investigated, as well as the effect of blowing through holes near the blade leading edge.

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2.12a	D. Arnal J.C. Juillen	Résultats experimentaux relatifs à l'influence des processur de transition sur la structure initiale d'une couche limite turbulent. ONERA TP 1979-128
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2.12c	C. Gleyzes J. Cousteix J.L. Bonnet	Bulbe de décollement laminaire avec transition (théorie et experience). ONERA TP 1980-20
2.16a	H. Fasel	Numerical solution of the complete Navier-Stokes equations for the simulation of unsteady flows. Proc IUTAM Symp 'approximation methods for Navier-Stokes problems', Paderborn. Springer-Verlag
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3 BOUNDARY LAYER EXPERIMENTS
Editor: B. van den Berg

The section contains 30 jobs, including five new ones. Also five jobs are reported completed (items 3.10, 3.11, 3.22, 3.23, 3.32) and one (item 3.4) is to be deleted as no report was received for the second year. The jobs to be discussed are divided into basically two-dimensional and three-dimensional turbulent boundary layer experiments.

Two-dimensional and axi-symmetric flows

Bradshaw, Imperial College, London, reports further measurements in a boundary layer on a concave surface of mild curvature (item 3.3). Turbulence measurements are now in progress, using hot wires. The measurements comprise the turbulence stress tensor components as well as triple products. Data are being taken at one pre-curvature station and at one streamwise position on the concave wall. In view of the presence of Taylor-Gortler vortices, several transverse positions will be applied. The measurements will be followed by a study of the turbulent/non-turbulent interface of the boundary layer. The aim is to learn about the effect of longitudinal curvature on the large eddy structure.

No further boundary layer measurements on a wing with flap have been carried out by Van den Berg, NLR (item 3.8). The issue of the report on last years tests has been delayed.

Delville, Serou and Tsen from the University of Poitiers investigate experimentally and theoretically the turbulent flow in inlets (item 3.14). Velocity and pressure fluctuations are being measured in an inlet. A publication on the theoretical work is available[3.14a]. Fohr from LDF, Poitiers, reports no new results (item 3.15).

The investigation of hypersonic turbulent boundary layers by Harvey, Hillier and Bartlett, Imperial College, London, is continuing (item 3.9). The turbulent boundary layer on a sharp cone in a Mach 9 flow is being studied. In addition to total temperature and total pressure surveys in the boundary layer, measurements of the fluctuating and mean density are to be made using the electron beam technique. Also surface pressure, heat transfer and skin friction will be determined.

The new job of Fernholz, Vagt and Dengel, Technical University of Berlin, regards an investigation of an incompressible turbulent boundary layer with nominally zero skin friction (item 3.42). The boundary layer to be investigated develops on a circular cylinder (axis parallel to the flow) on which the pressure distribution can be adjusted. The pressure distribution required for a zero skin friction condition was established by trial and error. Preliminary measurements of mean velocity profiles have been performed. Measurements of mean and fluctuating velocities, shear stress and skin friction will be carried out in the future, using hot-wire and pulsed-wire anemometry. Two former publications are mentioned[3.42a&b].

Further, there is a new job from Squire, Cambridge University, who studies boundary layers on nacelle afterbodies in the presence of jets (item 3.43). The object of the work is to study the effect of the jet on the entrainment into the boundary layer on the afterbody and to predict the overall drag.

Another new job, which is from Chauve and Dumas, IMST, Marseille, regards the turbulent flow in a duct with a weakly wavy wall (item 3.44). Measurements have been made in a duct of circular cross-section with wavy wall. The flow is a complex one: wall curvature effects occur, acceleration and deceleration takes place and even separation downstream of every crest. Flow visualisations have been made. Simultaneous flow calculations, based on the K-ε model will be performed by Schiestel. Three publications on this work have been issued[3.44a-c].

Finally there is a new job from Firmin, RAE, Farnborough (item 3.45). The boundary layer and wake on and behind a two-dimensional airfoil model at high subsonic speed are investigated. Measurements have been made at conditions, where no regions of separation exist, but where a significant drag creep was previously established. The two-dimensionality of the flow was investigated. It was found that there is no significant spanwise convergence or divergence. A publication on the latter results is available[3.45a].

Three-dimensional flows

Firmin, RAE, Farnborough, is also performing boundary layer and wake measurements on and behind swept wings at high subsonic speed (item 3.7). A report has now been published on the earlier measurements on a swept conventional (RAE 101) airfoil section[3.7a]. Measurements were made with a three-hole yaw meter not aligned with the local flow. Results have been compared with calculation results, using an integral method for three-dimensional boundary layers and wakes. Measurements were also made on a swept rear-loaded airfoil section. The latter experimental data are now being reduced. The measurements comprise two flow conditions: a predominantly subcritical flow and a mixed supercritical-subcritical flow.

Measurements in a three-dimensional boundary layer and wake on and behind a swept wing at low speed have been carried out at CERT, Toulouse by Michel and Cousteix (item 3.36). The experiment is reported to be completed. Tabulated data are available on request[3.36b&c]. The experimental data comprise: the static pressure distribution, the magnitude and the direction of the velocity in boundary layer and wake, the turbulence stress tensor at a few stations. The turbulence measurements were checked at one station in the wake by using a slanted wire probe as well as an x-wire probe, both rotatable around the probe axis. A fairly good level of agreement was found. A thesis on the work has been issued[3.36a].

The three-dimensional boundary layer on a swept wing in flight is being measured by Bertelrud, FFA, Stockholm (item 3.31). The results of some preliminary flight tests have been published[3.31a&b]. The main flight tests have started very recently. Extensive instrumentation is employed to document the viscous flow from the attachment line backwards to 70% chord.

Measurements in the rear-wake behind an infinite swept wing have been performed by Bradshaw, Imperial College London (item 3.37). The measurement results, including temperature-conditioned sampling with the boundary layer on one surface heated, are now being analysed.

Another job from Bradshaw, Imperial College, London, is the investigation of the structure of three-dimensional turbulent boundary layers (item 3.1). Detailed measurements have been carried out in a near-replica of the NLR test set-up. The final analysis of the hot wire data is now in progress. The results confirm a decrease in the ratio of the turbulent shear stress magnitude to the turbulent energy. The evaluations of the terms in the transport equations, however, have not yet been completed. Limited measurements may be made in the future in a flow with a larger pressure gradient.

At DFVLR, Göttingen, Meier and Kreplin are investigating the three-dimensional (laminar and turbulent) boundary layer flow on an inclined ellipsoid (item 3.35). Two angles of attack and two free-stream velocities have been applied. Surface hot film probes were used to determine magnitude and direction of the wall shear stress at various stations. The wall streamlines were derived from an integration of the measured wall shear stress directions. Transition regions and separation lines have been established. First mean velocity measurements in the three-dimensional boundary layer have been carried out. Four publications[3.35a-d] have been issued. Bippes, also from DFVLR, Göttingen, performs flow visualisation studies on a geometrically similar ellipsoid in a water towing tank (item 3.34). In order to compare with theoretical results, the flow in the plane of symmetry is studied in more detail, especially through visualising the velocity profiles.

Squire, Cambridge University, is doing measurements in two- and three-dimensional turbulent boundary layers near separation (item 3.38). Work is reported to continue. Two developments to separation have been studied up to now. An investigation on the effect of a step, simulating a gap between an airfoil and a flap, has just started.

The boundary layer flow near wing tips is studied by Horton, Queen Mary College, London (item 3.39). Detailed distributions of the surface pressure have been measured in the tip region of a wing model (NACA 0015 section) over an angle of attack range from 0-10°. A preliminary investigation of the viscous layer around the top is currently being made, using a small five-tube yaw meter, to determine the general flow pattern and to establish the regions of interest for a more detailed future investigation. Surface flow visualisation has also been carried out.

No progress with further measurements in three-dimensional turbulent boundary layers is reported by Felsch, University of Karsruhe (item 3.5). No report was received on the jobs 3.12 and 3.33 from Larsson and Löfdahl, SSPA and Chalmers University, on ship boundary layers, but work is known to be progressing.

There is a new job on ship boundary layers from Kux and Wieghardt, Shipbuilding Institute of Hamburg (item 3.46). To supplement previous measurements in the boundary layer on a ship double model in a wind tunnel, the stern flow including the wake is now being measured. Mean velocity measurements are being carried out with a five-hole tube at various streamwise planes on a fine cross-wise grid, so that all nine velocity gradients can be determined. In the outer part of the boundary layer and in the wake the acceleration terms almost cancel and the turbulent stresses are relatively small. In the nearwall region at the stern hot wire tests are planned. One publication is available already[3.46a].

Ingelman-Sundberg, FFA, Stockholm, studies boundary layers on wings with high-lift devices. In job 3.40 an untapered 30° swept wing with a leading flap is considered. A report is in preparation[3.40a]. In job 3.41 a 25° swept wing with leading edge droop is studied. Various spanwise distributions of the amount of droop have been investigated. Tests are concluded.

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3.14a	P. Serou L.F. Tsen	Finite element solution of the general turbulent flow in a duct. First Indian Congress of Fluid Mech, Bangalore (1980)
3.31a	A. Bertelrud	Measurement of local skin friction and static pressure on a swept wing in flight. FFA TN AU-1370 (1979)
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3.35a	H.U. Meier H.P. Kreplin	Experimentelle Untersuchungen von Ablösephänomenen an einem rotationssymmetrischen Körper. DGLR Jahrbuch (1979)
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3.35d	H.U. Meier H.P. Kreplin	Experimental study of boundary layer velocity profiles on a prolate spheroid at low incidence in the cross section $X_o/L = 0.64$. Proc 5th US-FRG DEA Meeting, Annapolis (1980)
3.36a	G. Pailhas	Couche limite et sillages turbulents tri-dimensionelle-champ moyen-tension de Reynolds. Thesis (1979)

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3.36c	J. Cousteix G. Pailhas	Three-dimensional turbulent boundary layer over the upper surface of an 'ONERA 5D' profile at angle of attack and sweep, tabulated data. Available on request
3.42a	H.H. Fernholz P. Gibson	Experiments on turbulent boundary layers along a circular cylinder with and without separation. MIT Gas Turbine Lab, Rep 91 (1967)
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4 THEORY AND EXPERIMENTS ON THE STRUCTURE OF TURBULENT SHEAR FLOWS

Editor: J. Cousteix

Five new items are described in this section (4.52-4.56). Two of them are related to the turbulence modelling by using the multi-scales concept introduced by Launder (4.52, 4.53). Item 4.54 is concerned with buoyant jets. Item 4.55 is a review of turbulent wall jet data and item 4.56 is a study of the structure of wall boundary layers. No response came for items 4.13, 4.29 and 4.33.

For the purpose of this section the items are divided into two groups: (1) turbulent shear flows: theory and experiments, (2) atmospheric and geophysical phenomena.

Turbulent shear flows: theory and experiments

Item 4.52 reported by Schiestel, Dumas IMST, Marseille is new. It deals with the turbulence modelling and the numerical prediction of turbulent flows. Several directions are being investigated.

(1) A new method of closure in turbulence modelling employing two or more independent time scales has been developed in collaboration with B.E. Launder. These time scales given by transport equations are used to characterise the different turbulent interactions. The physical model is based upon a spectrum splitting into two regions. The range of applicability of the model includes non equilibrium situations and numerical results show improvement over conventional single scale models[4.52a-c].

(2) Several numerical studies of turbulent complex flows are being developed in relation with experiments carried out at IMST. The reorganisation of the turbulent boundary layer subjected to sudden transverse strain is analysed. Calculations are also being carried out with a $K-\varepsilon$ model for predicting the turbulent flow on wavy walls.

The study reported by Cousteix, CERT, Toulouse (item 4.53) is also new. A multi-scale transport equation model is being studied following the ideas developed by B.E. Launder. A first step consists of an eddy viscosity model in which the turbulent kinetic energy is calculated by using two equations (one for K_p in the production zone and the other one for K_t in the transfer zone) and a distinction is made between the disipation rate $E_t = E$ and the transfer rate E_p of k: these two quantities are calculated by two separate equations. Two time scales are introduced K_p/E_p and K_t/E_t. The second step is to use two sets of equations for all the Reynolds stress tensor components: one for the production zone, the other one for the transfer zone. The models are being applied to several homogeneous flows (pure strain flows, shear flows ...).

At University of Eindhoven, de Vries - Krishna Prasad (item 4.56) theoretical and experimental work is being carried out. The turbulent transport by coherent structures in wall boundary layers is being studied. The theory presented in the PhD thesis of A.C.M. Beljaars has been examined heuristically to explain the behaviour of more complex turbulent boundary layers[4.56a]. Calculations to verify some of these conjectures will be taken up shortly. Concurrently work on the boundary layer development behind a step in surface roughness is in progress from three points of view:

(a) The length scale distributions as relevant to wind tunnel flows are being computed using the length scale equation proposed by Bradshaw in conjunction with his prediction method.

(b) Turbulent quantities have been measured in a water channel using the hydrogen bubble technique.

(c) As an aid in conditional averaging experiments in a wind tunnel boundary layer, a programme for burst detection has been developed using ideas of pattern recognition for analysing U-signals; attempts to incorporate features from the smoothed as well as high frequency part of the signal on the basis of kinetic energy.

The study carried out by Persen, University of Trondheim, item 4.39 is a longrange examination of theoretical as well as experimental results obtained in investigation of two-dimensional turbulent flows. The aim is to pursue an idea that eventually will bring such flows 'under one hat'. During the fall semester 1980 an experimental investigation will be undertaken.

At IMST, Marseille, Dumas Fulachier (items 4.10, 4.11) the study of the structure of turbulent flows is developed in several directions:

(i) Visualisation and laser-Doppler anemometry in a hydrodynamic tunnel[4.10a].

(ii) Turbulent flow in a wavy pipe with and without suction at the wall[4.10b].

(iii) Structure of turbulence in a boundary layer[4.10c]. The role of ejections and sweep flows has been particularly studied.

(iv) Structure of complex flows. The distortion of the axisymmetric turbulent boundary layer along a circular cylinder introduced by the rotation of the downstream part of the cylinder provides three-dimensional effects and a complex situation. Attention has been paid to the region very close to the wall (sublayer and buffer layer) where the major part of the influence of rotation occurs. Rotated single hot wire measurements have been carried out. A comparison with $K-\varepsilon$ model calculations has been made[4.10e-g].

(v) Turbulent combustion of air and propane: first measurements of mean temperature have been performed up to 1400 K with a thermocouple. Some measurements were also performed with a cold wire up to 700 K. The cold wire thermometry time lag has been checked by a laser modulated beam.

Maye, L.D.F. Poitiers (item 4.23) reports that new measurements of multi-order moments between velocity and temperature fluctuations have been carried out; they are given in a thesis by J.B. Vallet[4.23a]. The experimental methods which have been developed will be used for measurements of thermal turbulent fluxes in stratified flows.

Work reported by ECL is given in several items in the present section (items 4.25-4.27). Other information is given in item 5.18.

The study described in item 4.25, Gence-Loiseau-Mathieu is concerned with the response of turbulence to plane strains. The return to isotropy of turbulence which has been submitted to the two successive plane strains has been considered experimentally.

It has been shown that during the return to isotropy the directions of the principal axes of the Reynolds stress tensor remain constant so that it can be concluded that the principal axes of the non linear part of the pressure - deformation correlation tensor are the same as those of the Reynolds stress tensor, as is often assumed in closure models.

In the same context of homogeneous turbulence the action of a pure rotation on an initially non-isotropic turbulence has been studied by means of Craya's equation. Several publications on these topics are available[4.25a-e].

Item 4.26, Comte-Bellot, Sabot, is concerned with an experimental study of the coherent structures in turbulent pipe flow with a particular emphasis on the detection of the ejections and sweeps. Two new publications are available[4.26a&b].

Item 4.27, Charnay, Mathieu deals with experimental results involving scolar transport in a turbulent boundary layer. Upstream of a given station the wall is heated but thereafter the wall is maintained at ambient temperature. Temperatures and velocities are chosen so that buoyancy effects become significant. The temperature diffusion is analysed by means of the statistical fluctuation moments and by the production terms of the temperature variance. The diffusion of aerosol particles which are injected at different sections in the boundary is investigated[4.27a].

Several studies are reported by Bradshaw, Imperial College (items 4.14, 4.19, 4.47 and 4.48) in this section as well as in other sections (items 3.1, 3.3, 3.37, 10.7 and 14.21). A paper on merging mixing layers in the initial region of a jet has been submitted for publication[4.14a]. A calculation method for near wakes of aerofoils has been developed as an MSc project and is being incorporated into the higher order viscous-inviscid matching programme (item 4.19). The general programme of study on compled flow has continued. Most of the work is experimental but with direct application to calculation methods. The main computational work at present is on viscous-inviscid interaction with large normal pressure gradients (near trailing edges or flap knuckles, for example). The wake calculation has been incorporated into the viscous-inviscid interaction programme and it is nearly ready to run some test cases. Some preparatory work has been done for three-dimensional cases. Extensions to multiple aerofoils are planned.

The study described in item 4.47 is on conditional sampling of turbulent flow. Work on the comparison of temperature and velocity based techniques for intermittency determination has been concluded[4.47a]. Of the three plausible 'velocity' intermittency schemes tested, one has been found to show good agreement with the 'temperature' scheme, although inevitably there are definite but minor discrepancies between the two. A study of the turbulent burst length statistics at low and high Reynolds numbers in the boundary layers has been reported in Ref 4.47b. The concept of conditional probability was used in the study of the influence of 'hold-time' (the choice of the minimum length of irotational or rotational burst length admitted in the detector scheme) on the probability density functions of burst length statistics. Similar studies were conducted on the effect of the free stream turbulence. The effects of the free stream turbulence on the probability density functions are striking, further conditional sampling work is in progress, using a hot wire rake (single wire and cross wire) and also a hot and cold wire rake. The object

is the study of the pressure strain term in the Reynolds shear stress equation via measurements of the forcing terms in the Poisson equations for pressure. Measurements in a mixing layer approaching a solid surface, as in the initial region of a wall jet, have been written up as a PhD thesis[4.47c]: further analysis and preparation of a journal paper are in progress. Large changes in turbulence structure occur and may be partly responsible for anomalous results obtained with two-stream mixing layers in shallow wind tunnels.

Work described in item 4.48 is concerned with an experimental study of a longitudinal vortex imbedded in a turbulent boundary layer. Most of the data have now been analysed and a detailed report is in preparation. Apart from measurements of all the mean quantities, including flow directions, detailed measurements of all the turbulent quantities including all the Reynolds stresses and relevant triple products have been made. It will also be possible to obtain a map of the intermittency, evaluated from velocity fluctuations. A limited exploration of a slightly heated vortex has been carried out so that intermittency could be deduced more easily, from the temperature fluctuations. On the other hand, a suitable configuration for a vortex pair, with fluid in between moving away from the surface, has been established using two half-delta wings mounted in the setting chamber of a blower tunnel. Detailed measurements are about to begin, and will be followed by an experiment on a vortex pair with the common flow moving towards the surface, again using a pair of half-delta vortex generators.

From Chassaing, Ha Minh, Boisson, Sevrain, IMFT, (item 4.45) two publications are given. One is concerned with numerical problems in calculations of recirculating flows[4.45a]. The other is concerned with an experimental study of the vortices generated by a cylinder[4.45b].

At University of Brussels, Hirsch, (item 4.31) a conditional sampling and averaging technique has been developed. It is used for the detection and analysis of the coherent structures found in turbulent boundary layers. A multichannel data-logger and a min-computer with digital tape drive were used to implement this technique[4.31a]. The first results were obtained in a zero pressure gradient boundary layer and they showed good agreement with results obtained by others. The technique is now being applied to boundary layers with non-zero streamwise pressure gradients, both accelerating and decelerating.

Rodi, University of Karlsruhe, (item 4.55) in cooperation with B.E. Launder has reviewed experimental data for turbulent wall jets for the 1980/1981 Stanford Conference on Complex Turbulent Flows[4.55a]. The review was restricted to two-dimensional isothermal wall jets, and the following flows were considered in detail: self-preserving wall jets on flat surfaces with and without free stream, wall jets on flat surfaces in constant free stream and in free streams with pressure gradient, curved wall jets on cylindrical and spiral surfaces. The two-dimensionality of the data and the general reliability were checked and the most reliable data have been identified and suggested at test cases for the 1981 conference.

The following items deal with effects of particular perturbations of a turbulent flow: curvature effect (item 4.36), free stream turbulence (items 4.34, 4.1, 4.37),

relaxation after separation or reattachment or after a step change in wall roughness (item 4.50), sudden expansion (item 4.43), three-dimensional effects (item 4.44).

At University of Berlin, Fernholz, Vagt, Hartmann, (item 4.36) the experimental investigation of the influence of upstream conditions on the deflection of a curved wall jet is continuing. In the upstream section of the test rig the contraction was replaced by a duct in order to investigate further the influence of laminar and turbulent flow regions on the deflection of the wall jet. It was found that the turbulent duct boundary layer relaminarised for certain conditions of the spoiler which was situated at the duct exit opposite the curved wall. This means that a fully turbulent curved wall jet is deflected less on a curved wall than one which has a laminar or relaminarised region close to the wall.

At the DFVLR, Gottingen, experimental and theoretical investigations are being continued on the influence of the wind tunnel turbulence Meier, Kreplin (item 4.34), Rotta (item 4.1). The theoretical approach uses second order moment closure assumptions[4.1a]. The free stream turbulence field is assumed to be homogeneous with respect to planes normal to the direction of the undisturbed flow and is described by the intensity and the integral length scale. The partial differential equations for the two-dimensional flat plate boundary are integrated using a finite difference procedure. Numerical results of the development of the boundary layer are shown and the effect of intensity and length scale on the velocity profiles is discussed. A new publication on the experimental results is now available[4.34a].

Work reported by Lewkowicz, University of Liverpool, (item 4.37) has progressed in the direction of appraising the effects of the external turbulence upon the development of the wall shear flow beneath it.

At University of Bochum, Gersten, (item 4.50) further experiments are being conducted, both in channel flows and in boundary layer flows subject to a disturbance. Attempts are under way to extend the theoretical framework for shear flows when the disturbance to the turbulence structure arises at an arbitrary location within the shear layer, not necessarily at the wall.

The study reported by Dussauge, Gaviglio, De Bieve IMST Marseille, (item 4.43) on the analysis of the Reynolds stress evolution in the case of supersonic flows has been continued. It has shown that the mean density changes do not modify the Reynolds stress anisotropy; they do not contribute to the rapid (linear) part of the pressure-strain correlation terms if the velocity fluctuation field is solenoidal. The limitations of the validity of the models proposed by Lumley and Launder has been examined. On the other hand, experiments[4.43a] are being performed in a turbulent boundary layer ($M = 1.77$) accelerated through an expansion fan (deviation angle = 12^{o}). Mean flow measurements show that the mean velocity profiles do not correspond to an equilibrium state at a distance of ten times the initial boundary layer thickness. Nevertheless, the formation of a new log velocity profile is found. Measurements of turbulence intensities of velocity, temperature and of the velocity-temperature correlation coefficient are carried out upstream and downstream of the expansion; the velocity temperature correlation

coefficient remains practically unchanged in the interaction. An analysis of the 'strong Reynolds analogy' has been performed in order to define the conditions under which this analogy remains valid. It has been shown that it is valid even in flows subjected to pressure gradients, if the total enthalpy fluxes are low enough[4.43b]. Another investigation involves the effect of a shock wave on turbulence[4.43c].

Experiments reported by Krause, Tsiolakis, University of Aachen (item 4.44) on measurements of the Reynolds stresses in a three-dimensional turbulent boundary layer are described in two new publications[4.44a&b]. A new probe has been constructed and it will be used in flows with high turbulence intensity. At present, comparison measurements are being carried out in a two-dimensional turbulent boundary layer upstream of a forward facing step[4.44c].

Atmospheric and geophysical phenomena

Work reported by Rodi, University of Karlsruhe, (item 4.46) on the calculations of three-dimensional heated surface jets has now been published[4.46a]. The three-dimensional calculations of coaxial and side-discharges of heated water into open channel flow continue. In the meantime these flows were studied experimentally in a flume, and a report is available on the results[4.46b]. The work on calculating internal hydraulic jumps also continues. The calculations of buoyant water jets along adiabatic and vertical walls is complete and the report will be available shortly. The buoyancy extended turbulence model simulates well the buoyancy effects in both cases. Hossain has completed his PhD thesis[4.46c] on the development of a buoyancy extended version of the $K-\varepsilon$ turbulence model, and successful applications the model to the following situations are reported in the thesis; plane and axisymmetric vertical buoyant jets in homogeneous and stably stratified environments, two-dimensional heated surface discharge in stagnant waters (in particular the reduction of jet entrainment by buoyancy is well simulated) coaxial heated surface discharge into channel flow (the reduction of vertical mixing by buoyancy is simulated) and plane wake in stratified environment, where the wake spreading is significantly reduced by the stable stratification. The work on heated discharge into channel flow is also reported in Ref 4.46d. Further buoyant flow calculations will be carried out with the newly developed numerical schemes for unsteady two-dimensional flow reported in section 1. This unsteady code will be used to calculate the time-dependent development of density currents and the behaviour of stratified flow under tidal conditions in estuaries. An experimental study is also being carried out on a buoyant jet in shallow water. Buoyancy is achieved by discharging warm water and the temperature distribution is measured with thermistor-probes, while the velocity field is measured with a two-channel laser-Doppler anemometer.

Work reported by Fanneløp, Krogstad, University of Trondheim, (item 4.49) is concerned with the gravitational spreading of heavy gas clouds. A pilot experiment of gravitational spreading has been completed. Liquid nitrogen was evaporated at one end of a 2.5m x 25.0m two dimensional channel and certain cloud characteristics (frontal speed, velocity and temperature distributions, concentration) were measured. It appears that the usual entrainment models are inadequate, but additional experiments are required to

establish viable alternatives. An interim report has been published[4.49a]. A theoretical study of gravitational spreading in a quiescent atmosphere has been completed and the report has been prepared. Similar and quasi-similar solutions have been developed for a heavy cloud with and without entrainment. In addition, certain integral solutions based on assumed profiles of height, density and velocity have been explored. An early report[4.49b] is being revised and is nearly ready for distribution.

Linde, FFA Bromma, (item 4.51) reports that an experimental verification of the gust model in the atmospheric boundary layer is being aimed at. For this purpose turbulence measurements in the atmospheric boundary layer will be analysed with conditional sampling techniques in order to detect gust structures.

At Imperial College, Bradshaw, (item 4.30) the development of a calculation method for neutral plumes using transport equations for turbulent concentration flux rates has been completed: empirical input has been taken from wind tunnel measurements of Nakayama (unpublished). A report has been written up[4.30a].

Work reported by Schatzmann, University of Karlsruhe, (item 4.54) is a new entry in this section. It deals with the derivation of the integral conservation equations for buoyant jets with three-dimensional trajectories. In Ref 4.54a it is demonstrated that several of the existing models which are nowadays widely used for the design of outfall structures are based on erroneous equations. The objectives of the work presented in the report is to derive the integral conservation equations for submerged buoyant jets with one-, two- and three-dimensional trajectories from the fundamental partial differential equations and to illuminate the errors of the former approaches.

Stevenson, University of Manchester, (item 4.42) reports that attention is now directed towards the study of internal waves in thermoclines. A publication on viscous effects in lee waves is now available[4.42a].

Item 4.32, Rheinlander, University of Berlin, deals with the turbulent convection of air in closed rooms. The computer programme has been generalised and may be used to study all types of time dependent air flows in rooms where two-dimensional behaviour is dominant. The prediction of velocity and temperature profiles in boundary layers and jet cores is not very good when refinements such as the logarithmic wall function and correction functions for jets can not be used. Nevertheless calculations of the overall effects of such flow elements on air flow in rooms satisfy the requirements of air conditioning applications. A new publication is available[4.32a].

Nerault, LDF Poitiers, (item 4.28) is beginning to test a new wind tunnel designed for obtaining a thermally stratified field. The main characteristics of the test section are: length 5 m, width 0.2 m, height 2 m. The maximum velocity is 15 m/s. An air-heater (200 kW maximum) can produce a vertical temperature gradient of about 40°/m. A system of non uniform grids gives different velocity profiles in the vertical direction.

At the LDF, Poitiers, Penot, (item 4.41) velocity measurements have been performed within the thermosyphon flow by using a laser Doppler anemometer. The velocity profiles show the occurrence of reverse flows in the inlet part of the duct, when the temperature

difference increases. The measured flow rate agrees well with the theoretical results. A publication is available[4.41a].

At University of Eindhoven, de Vries (item 4.9), measurements in the atmosphere with a three-wire probe to obtain information on momentum and heat fluxes over grasslands are being analysed.

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5 PREDICTIONAL METHODS FOR TWO-DIMENSIONAL BOUNDARY LAYERS

Editor: W. Kordulla

The number of job items remains constant in spite of three new jobs (5.30-5.32). Three jobs have been deleted since they have been completed or discontinued: Williams, RAE, Farnborough (item 5.5), Jischa, University of Essen (item 5.22), and Dyne, SSPA, Goteborg (item 5.23). One other job will be deleted next year because no response has been received for the second year: Gampert from the University of Essen (item 5.27). No response was further received by Dekeyser from IMST (item 5.7). Horton, UIQMC (item 5.21) reported no progress. A general trend to include inviscid-viscous interactions and normal-pressure gradients is evident.

Michel, Cousteix, and Houdeville from CERT-DERAT, Toulouse (item 5.8) emphasise the development of inverse integral prediction methods which are being applied to a variety of two- and three-dimensional problems. Livesey from the University of Salford (item 5.25) with two references continued the work as was described in the 1979 report. Additionally calculations are being made for some RAE test diffusers, for comparison, with detailed attention to loss prediction. Convergence is reported to no longer be a difficulty. Dyne from SSPA (item 5.29) used his method to calculate the boundary layer and wake of a flat plate and two-dimensional airfoils. The agreement with experiment was good. The influence of Reynolds number on the drag components of the airfoils has also been studied. A report describing the method and the calculation results is being prepared.

Krause and Hänel from THAAI (item 5.13) continued their work on shock-boundary-layer interaction in two-dimensional transonic flows past airfoils as influenced by tangential shot injection. The solution is extended to separated flows by considering the wall-normal momentum equation near separation. Three references are reported. Gersten from the Ruhr-Universität Bochum (item 5.28) reports the use of matched asymptotic expansions to study theoretically the dispersion of interior waves in viscous fluids. Experiments have also been conducted with an oscillating cylinder in a vessel containing a liquid whose density varied linearly with the depth. Using a schlieren interferometer, the experimental verification of the asymptotic theory for large Reynolds numbers was possible[5.28a].

Harvey from ULIC (items 5.24 and 5.26) reports for job 5.24 that the electron-beam study of the flow ahead of a blunt cylinder is nearing completion, and that computations are being made of the flow over a family of blunted cones using the Monte-Carlo technique. This technique is also used for job 5.26 to determine the structure of the impingement region of two intersecting plane shockwaves.

The three new jobs are as follows: Ackroyd from the University of Manchester (item 5.30) investigates turbulent boundary layers on axial slender cylinders. An analysis has been performed for the turbulent flow equivalent of the laminar flow case studied earlier by Glauert and Lighthill and by Stewartson. Turbulent flow experimental velocity profile correlations, originally due to Rao, are used in conjunction with the integral momentum equation to produce an expression for the axial distance along the cylinder in terms of the skin friction coefficient. This frequently used approach yields double

integral expressions which usually are evaluated numerically. However, reversal of the sequence of integration reduces the problem to a single integration. The results have been compared with an earlier analysis along these lines due to White which is shown to contain algebraic errors and with the available experimental data for drag.

The second new job is conducted by Livesey, Myring and Weir from the University of Salford (item 5.31), and concerns the prediction of high-speed turbulent boundary layer flows (originally job 8.27) which cannot be adequately treated using standard boundary layer methods. Transverse and longitudinal radii of curvatures which are not large compared with boundary layer thickness are considered and specific interest is given to the prediction of normal pressure gradients. Finite difference equations for two-dimensional and axisymmetric flows are employed together with several existing treatments of turbulent structure. Although the governing equations are essentially parabolic, work is currently focussed on the tendency to an elliptic character in the outer flow away from the wall. Supersonic interior flows are also to be considered. Finally Rodi from the University of Karlsruhe (item 5.32) is developing a calculation scheme for boundary layers on turbine blades to give the distribution of heat transfer coefficients around the blades. First, a program will be developed for isothermal boundary layers which can handle effects like free stream turbulence, wall curvature, roughness, longitudinal pressure gradients and also the transition laminar/turbulent as well as possible relaminarisation. The calculations are carried out with a modified version of the Patankar-Spalding programme, and a low Reynolds number version of the $K-\varepsilon$ turbulence model is used to determine the turbulent transport properties. First results have shown that the influence of strong acceleration (leading to relaminarisation) and a free stream turbulence can be well simulated by this turbulence model.

Jeandel, Gence, Cambon, Mathieu, Brison, Papailiou and Gay report five references this year. They have developed a spectral method to calculate homogeneous anisotropic turbulent fields associated with a mean velocity gradient. In addition, a fast convergent method to solve the incompressible laminar viscous flow governed by the Navier-Stokes equations (developed by Glovinski et al) has been applied to account for additional coupling source terms and various boundary conditions.

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6 PREDICTION METHODS FOR THREE-DIMENSIONAL BOUNDARY LAYERS
Editor: W. Kordulla

This year the number of jobs is 19 versus 18 last year as a result of two new jobs and one deleted one, Hoekstra from NSP (item 6.30) which has been completed. Little or no progress is reported by Kux from the University of Hamburg (item 6.2), Fannelöp and Humphreys from the FFA (item 6.7), Krause from the University of Aachen (item 6.10), and by Bertelrud from FFA (item 6.17). Kruase, however, reports two reviews on viscous-flow computations[6.10a&b]. Larsson from SSPA (item 6.29) organised the SSPA-ITTC (International Towing Tank Conference) boundary layer workshop at Gothenburg in early June, in which several Eurovisc-contributors participated. A total of 13 references are reported versus 14 last year three of which were reviews[6.10a&b,6.11a]. Here, again as in section 5 a trend towards the inclusion of higher-order effects and inviscid-viscous interaction can be noticed.

Smith from RAE Bedford (item 6.3) reports that they now have a working finite-difference method in addition to his (lag-entrainment) integral prediction method. Michel and Cousteix from CERT-DERAT, Toulouse (item 6.5), have shown that the set of global incompressible integral equations (closed by similarity relations) are totally hyperbolic, and that one of the characteristic lines coincides with the limiting wall streamline. This forms the base for their investigation of singularities due to streamline focussing (also present in two-dimensional unsteady flows). A new inverse method is shown to avoid such singularities, and to cope with separation phenomena (one application, for example, is made to the vd Berg et al experiments). Stock from Dornier (items 6.27 and 6.28) reports that the results of the computation of the laminar boundary layer on inclined ellipsoids, based on an integral method, show excellent agreement with finite-difference solutions. An inverse integral method for calculating turbulent, separated boundary layers on infinite swept wings has been developed. This method uses Coles velocity profiles for the streamwise direction and, in spanwise direction flat plate (zero pressure gradient) velocity profiles. The calculations show very good agreement for the van den Berg and Elsenaar test case.

Elsholz from VFW (item 6.33) focuses his work on investigations based on Cousteix's three-dimensional integral turbulent boundary layer prediction method. The latter has been coupled with the VFW panel method via the surface transpiration concept. Preliminary results from such computations for subsonic flow without separation on a yawed wing at incidence, are encouraging. In a new job Hirschel, from MBB (item 6.34), is studying several integral and finite-difference boundary layer prediction methods for possible integration into aerodynamic design methods.

The remainder of this section concerns those contributors who, predominantly, use finite-difference prediction techniques. Lindhout, Elsenaar and vd Berg, from NLR (item 6.9), concentrated their activities during the past year on advancing the plotting capabilities of their code. They announce an extensive user's manual for the complete code. Schneider from the DFVLR, Göttingen (item 6.21), extended his method to treat the incompressible flow past axisymmetric ellipsoids at angle of attack using orthogonal

external-streamline oriented coordinates. For the laminar flow and several angles of attack the predicted results are compared with experimental data obtained at the DFVLR, Göttingen. Kordulla, from the DFVLR (item 6.11), made simular calculations using Stock's non-orthogonal coordinates for ellipsoids for the integration of the compressible boundary layer equations in contravariant form. Schwamborn (item 6.' reports that he managed to accurately predict the flow near the attachment line of winglike bodies at large angles of attack. The essential ingredient of the method is to combine two zig-zag finite-difference schemes with opposite orientation in an iterative manner[6.11b&c]. Schönauer, from the University of Karlsruhe (item 6.23), reports difficulties with the numerical evaluation of the metric coefficients which are computed from local approximations of the streamline coordinates (where the configuration is assumed to be given pointwise). The selfadaptive method reacts to very small jumps in the metric coefficients at the transition from one local approximation to the next (while the method without selfadaptation does not). Thus the need for a more and more 'intelligent' code arises. Results for a rotational ellipsoid are reported not to show the open separation found by Wang and by Geissler. Rodi at the University of Karlsruhe (item 6.26) reports that the diploma thesis on calculations of the cylinder-on-flat-plate case studied experimentally by Dechow and Felsch is now available[6.26a]. No further calculations are being carried out at present, but they will probably be resumed later this year. Hoekstra from NSP (item 6.31) has made attempts to incorporate transverse curvature effects in his code as well as to include viscous-inviscid interaction. It was not found useful to separate transverse from longitudinal curvature effects and to neglect the latter. The viscous-inviscid coupling procedure with first-order boundary-layer code is based on the surface transpiration concept. Convergence was obtained after six iterations in regions with fairly thin boundary-layers. In regions with vortex separation the iteration process was found to diverge. It was concluded that, in order to obtain reliable results for ship-stern flows, higher-order boundary layer methods are required. In a new job (item 6.35), Hoekstra has applied a fourth-order spline interpolation technique in order to reduce computation time and storage requirements. Five to ten mesh points across the boundary layer were sufficient to give excellent results for laminar flow predictions. For turbulent-flow predictions oscillations have initially been encountered a problem which remains to be solved. Humphreys at FFA (item 6.32) has coupled together a higher-order panel method and a three-dimensional boundary layer programme using the equivalent surface transpiration velocity boundary condition. A first test case has been run to five iterations and the composite flow appeared to converge satisfactorily. On a more difficult test wing calculations showed early separation whereas the flow was unseparated in the experiment. The current effort is on how to proceed with calculations in the presence of non-catastrophic separation.

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7 WAKES AND TRAILING EDGE FLOWS
Editor: T.K. Fanneløp

Two new items are included this year. Professor Thiede and coworkers at VFW-Fokker GmbH have been engaged for some time in studies concerning the trailing edge region of rear-loaded airfoils. A rather detailed discussion of this work, our new item 7.28, quoted from the job card, follows:

"Melnik's trailing edge flow concept, which includes normal pressure gradient and wake curvature effects and the strong viscid-inviscid trailing edge interaction, is adopted for an improved analysis of viscous effects on rear-loaded airfoils. For the consolidation of the present viscous flow solution, boundary layer and wake measurements in the trailing edge region of a supercritical airfoil are carried out in the 1 x 1m DFVLR Transonic Tunnel in Göttingen. For subsonic airfoil flow predictions an iterative procedure is developed, simulating the viscous effects by the surface mass flow concept. Further improvements of the iterative procedure were concentrated on:

- the formulation of the Kutta condition
- the determination of the wake curvature behind the trailing edge
- the inclusion of temporary separated regions near the trailing edge which appeared in the iterations
- the relaxation of the boundary conditions in the trailing edge region.

For airfoil flow predictions at transonic speeds, an iterative procedure will be developed in the future, using the subsonic precedure as a pilot one." Four publications are available giving additional details of this work[7.28a-d].

This new job is related closely to item 7.25 by Veldman and van den Berg (NLR, Amsterdam) which considers viscous flow over a sharp trailing edge with emphasis on the interaction with the potential flow. Again substantial progress has been made and the new developments are quoted from the job card:

"Calculations have been performed with a model problem for asymmetric trailing edge flow on basis of the laminar, incompressible boundary layer equations. It appears that in this case the classical Kutta condition still can be used to determine the circulation of the outer flow. A paper containing some results is to be published[7.25a]. Recently a start has been made with the extension to turbulent, compressible flow requiring the inclusion of normal pressure gradients. Two experiments have been planned to support this work:

(i) an experiment to determine the viscous lift loss of an airfoil under well-controlled conditions,

(ii) an experiment to determine detailed flow properties, including the turbulence stress tensor, in a simulated trailing edge region of large size.

The latter experiments will be carried out in close cooperation with the Technical University, Delft, Dept of Aeronautics." This work is related to research reported under item 10.32.

A continuing research study concerned with thin trailing edges (item 7.6) belongs to Solignac and coworkers (ONERA, Chatillon). Here an annular model is used both in theoretical studies and in related experiments. The new work on vortex wakes included in last year's entry, will be discussed here as the new item 7.27. Under item 7.6 it is reported that the wakes behind profile shaped bodies have been studied by numerical methods to check a simple mixing length model of turbulence for the various cases studied in the experiments. Included are (a) plane wakes without separation but with pressure gradients and disymmetrical initial conditions and (b) axisymmetric wakes centered on the axis or off the axis. The programme can run in a direct option (U_e is given) or in an inverse mode (δ^* is given). The velocity is well predicted in all cases. Some discrepancies appear at times between measured and calculated shear stress. From the numerical work it has become possible to estimate the effect of the transverse pressure gradient. Two new publications are available[7.6a&b]. The new item 7.27 by Solignac and Delery (ONERA, Chatillon) represents a spin-off from item 7.6 and the initial effort was in fact discussed as part of this job last year. The basic configuration is a body of revolution, rotating about its axis which produces a swirling axisymmetric wake. An experimental technique using a hot wire which rotates with the body has been developed to measure the mean velocity components as well as the turbulence quantities in this kind of flow. As reported this new job also includes (a) studies of vortex breakdown phenomena using a larger wind tunnel (diameter 0.1 m) where an adverse pressure gradient of variable strength can be imposed, and (b) studies of the interaction of a vortex with a quasi-normal shock wave ($M_\infty \sim 1.35$). The vortex is generated upstream of the supersonic nozzle throat. The interaction process is analysed by measuring the velocity field using a two-colour laser velocimeter. Concurrently, theoretical models have been developed using as a first step simplified equations of parabolic type. Integral as well as finite difference methods of solutions have been programmed.

A related study of compressible near wake flows, is the continuing investigation of Roquefort and Bonnet, CEAT, Poitiers (item 7.16). It is reported that:

"Space-time correlation are made with CTA giving some general information concerning the structure of the wake convection velocities, shapes of iso-correlation curves, characteristic scales, damping of correlation. Further information will be given by the study of intermittency and conditional measurements. Measurements of turbulent quantities ($\overline{T'^2}$, $\overline{T'u'}$, $\overline{u'^2}$, $\overline{u'v'}$, $\overline{T'v'}$) are to be achieved and will lead to check the predictions of the second order closure model." Two new publications are available[7.16a&b].

Horton of Queen Mary College, London (item 7.26), is studying the interaction of a wake and a developing boundary layer. The first stage of the experimental programme, ie the study of wake/boundary layer mixing on a flat plate, has been completed. Both symmetric and unsymmetric wakes were investigated and measurements of mean velocity, turbulence intensity and shear stress were made. These results are at present being analysed. The apparatus for the second stage of the programme, in which the effect of adverse pressure gradient on the mixing will be studied, is under construction. This consists of a main aerofoil/slat combination.

The long term study of Gibbings and Norbury, University of Liverpool (item 7.1), is concerned with thick trailing-edge flows and associated phenomena. This work continues. Extensive measurements have been made of the eddy shedding from the trailing edge. Hot-wire and optical techniques have been developed for this. Distinct relations have been found between the eddy-shedding and the base process with and without base blowing. The 1978 work is now described in an M Eng thesis.

The remaining two active studies deal with flow around circular cylinders. Zdravkovich, University of Salford (item 7.23), has investigated the flow phenomena encountered when a cylinder is placed near a plane boundary. As a special case he has recently considered 'the hydroelastic response of a pipeline near to or on a seabed of various roughness.' The object will be to measure the fluctuations in the oscillatory flow around a pipeline model both fixed and flexibly mounted. The main variables will be gap to diameter ratio, Keulegan-Carpenter number and natural frequency of the model. The project will be sponsored by the North West Consortium for Marine Technology. One new publication is available from work under this item[7.23a].

Ha Minh, Boisson and Martinez, IMFT, Toulouse (item 7.24), have published three new papers from work under this task[7.24a-c].

In all eight items remain active under the present heading and of these, two items are new this year. Item 7.18 has been completed and will be deleted. Item 7.19 appears to be active, but no detailed response has been received so far.

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7.6b	J.L. Solignac	Etude expérimentale du décollement un bord de finite d'un arriere corps de revolution profilé. Breve information la Recherche Aerospatiale No.1980-3
7.16a	Th.A. de Roquefort J.P. Bonnet	Caracterisation des structure dans un sillage turbulent supersonique. Contrat DRET 77/453, final report (1979)
7.16b	Th.A. de Roquefort J.P. Bonnet	Mesure des correlations spatio-temporelles dans un sillage supersonique. Contrat DRET 78/573, Technical Note (1979)

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7.24a	H. Ha Minh H. Boisson G. Martinez	Unsteady mixed convection heat transfer around a circular cylinder. Annual meeting of the ASME, Heat Transfer Division, Chicago, November 1980
7.24b	M. Braza H. Ha Minh H. Boisson	Ecoulement décollé instationnaire derriere des obstacles. EUROMECH Colloquium 135, Marseille, Octobre 1980
7.24c	H. Boisson A. Sevrain M. Braza	Statistiques sur les durées des épisodes turbulents au passage des tourbillons émis par un cylindre. EUROMECH Colloquium 132, Lyon, July 1980
7.25a	A.E.P. Veldman	The calculation of incompressible boundary layers with strong viscous-inviscid interaction. Colorado Springs, September 1980
7.28a	P. Thiede	Calculation of viscous effects on rear-loaded airfoils with consideration of a local trailing edge solution. DEA-meeting, Viscous and interacting flow field effects, Monterey, USA (1978)
7.28b	P. Thiede G. Dargel E. Stanewsky	Investigation of trailing edge flows on rear-loaded airfoils. DEA-meeting, viscous and interacting flow field effects, Meersburg/Bodensee (1979)
7.28c	E. Stanewsky P. Thiede	Boundary layer and wake measurements in the trailing edge region of a rear-loaded transonic airfoil. DEA-meeting, viscous and interacting flow field effects, Meersburg/Bodensee (1979)
7.28d	P. Thiede G. Dargel	Verbesserte Erfassung der Reinbungs-effekte im Hinterkantenbereich von überkritischen Profilen. FüFo IV, Forschungsbericht aud der Wehrtechnik T/RF 41/70022/71421, VFW-Fokker (1979)

8 FLOWS IN CORNERS, DUCTS AND ROTATING MACHINERY

Editor: P.D. Smith

The wide range of flow configurations with which the section is concerned have, as a common feature, regions in which the boundary layer approximations do not necessarily apply. There is no progress to report for items 8.2, 8.17, 8.23, 8.25, 8.28 and 8.35. Items 8.15, 8.20, 8.24 and 8.32 have been completed and will be deleted next year. For item 8.20 a final Ref 8.20a is given. Item 8.27 has been transferred to section 5 and is now item 5.31.

There are four new items this year, 8.37-8.40. In the first of these (item 8.37) Grundmann of DFVLR Göttingen is developing a calculation method for three-dimensional laminar flow through non-rotating cascades. The method uses the parabolised form of the three-dimensional Navier-Stokes equations for incompressible flow together with the continuity and energy equations. The energy equation is included in preparation for the extension to compressible flow and because it aids the numerical treatment of the crossflow equations. The method of solution is based on the ADI method and uses iteration to compute the average downstream pressure gradient. The coordinate system used is curved and non-orthogonal in the downstream direction. The crossflow section is assumed to be rectangular. Modification to real cascade configurations is considered possible.

In the second new item, 8.38, Frühauf of the University of Stuttgart is developing a method of solution for the Navier-Stokes equations in order to compute the turbulent transonic flow through blade rows. The object being to achieve more accurate prediction of the flow turning and losses in cases where there is a moderate interaction between the boundary layer and the external flow. In the method the time dependent Reynolds averaged Navier-Stokes equations are solved for the flow through plane cascades using the implicit Beem Warming method and well known (at this stage algebraic) turbulent models. The solutions are compared with accurate plane cascade experiments. The model has been tested for two-dimensional laminar flows. Extensions of the model to the flow along Wu's S_1-surfaces (including coriolis and centrifugal forces and the convergence of the meriodional streamlines) is planned. A Ref 8.38a is given.

For the third new item, 8.39, Felsch and Simon of the University of Karlsruhe have developed a prediction method for fully developed turbulent flow in rotating channels of rectangular cross-section. The channel rotates about an axis perpendicular to the direction of the mean stream. The coriolis forces induce a secondary flow in the cross-sectional plane which increases the total pressure losses in the channel. The method uses the Reynolds equations with vorticity and stream functions as dependent variables. Turbulence is modelled by the K-ϵ method. The equations are solved by a finite difference scheme using 20 x 40 points on half of the cross-section. The logarithmic law of the wall is used to model the flow close to the channel walls. Predictions have been made for Reynolds numbers from 10^4-10^6, rotation numers from 0-0.1 and aspect ratios from 0.5-5.0. Agreement between prediction and experiment is satisfactory. The method will now be applied to curved channels. A Ref 8.39 is given.

The fourth new item, 8.40, from Bork and Meijer of the Swedish Royal Institute of Technology and FFA respectively is an investigation of rapidly rotating gas flows. Two problems are currently under investigation. (i) the effects of circumferential curvature and strong radial stratification on a Stewartson E boundary or shear layer. This problem is almost finished and a report will be submitted for publication during autumn 1980. (ii) the spin up of a rapidly rotating gas in a cylinder with thermally insulated walls. The mathematical formulation of this problem has not yet been completed and the computer programme for the governing parabolic equation remains to be written. This problem is the time dependent extension of Ref 8.40e. In all seven Refs 8.40a-g are given.

Turning now to existing items Palm of the University of Oslo (item 8.18), reports that the investigation by Bertelsen of secondary flows in curved tubes has just been completed. Strong secondary flows were observed at the inlet to the curved pipe and detailed velocity profiles are contained in a masters thesis by L.K. Thorsen. A final report will be available during 1980.

Oertel of Karlsruhe (item 8.19), has continued his investigation of convection within a rectangular box. Three-dimensional calculations have been made and the predicted wave number selection of convection rolls within the box agreed with experimental results. Comparison with two-dimensional finite difference calculations has demonstrated that two-dimensional numerical models are valid for calculating the amplitude of the motion in the middle of the rectangular container. The integral heat flux through the convection box is, however, determined by the whole three-dimensional flow field. The aim of the current work is to contribute to the physical understanding of thermal turbulence. Optical measurements and numerical simulation of cellular convection at large Rayleigh numbers have permitted the separation of several steps of the transition to turbulence. Coherent turbulent structures in thermal boundary layers have been visualised using differential interferometry. The local densities and velocities were measured simultaneously with the laser-anemointerferometer described last year under Ref 8.19a.

Bradshaw (item 8.21) has published a set of design rules for small low speed wind tunnels[8.21a]. He also reports that some further investigations on screens have re-emphasised the differences between polyester and metal screens, presumably due to detailed differences in mesh geometry. There is strong support for the view that the open-area ratio of a screen alone is not enough to describe the quality of flow emerging from it. Several measurements have been made of spanwise skin friction variations in the test section boundary layer emerging from a variety of screen/honeycomb/tunnel combinations. A short paper outlining the results is in preparation. A detailed paper on the effects of gauze screens (metal and polyester) on turbulent flow is also in preparation. The investigation of the numerical prediction of diffuser flow behaviour by Livesey at the University of Salford (item 8.29), is now nearing completion. The extension to three-dimensions has only been considered in outline as very considerable limitations imposed by computer storage have been encountered. An improved treatment of the separation region is, however, under consideration. Also at Salford the first stage of the work on the decay of turbulent velocity profiles (Livesey and Laws (item 8.30)) has been completed

and is described in Ref 8.30a. For item 8.31, duct design for three-dimensional turbulent flow, Livesey and his co-workers have recently acquired some interactive graphics display equipment and will be applying additional effort to the calculation of three-dimensional boundary layer flows. To this end Myring has been added to the list of contacts.

The experimental investigation of the flow in rotating channels by Felsch of Karlsruhe (item 8.33), has resulted in a publication[8.33a]. Felsch reports that for large Taylor numbers the influence of curvature can be neglected. Only the coriolis forces lead to a pressure loss. By varying the cross section it has been shown that for large curvature and laminar flow the ratio between the channel height, h, and the channel width, b, is decisive in determining the size of the pressure loss. In turbulent flow the pressure loss coefficient is independent of the cross-section within the range $1/3 < b/h < 3/1$.

In their investigation of the flow of highly viscous fluids between rotating discs (item 8.36), Felsch and Piesche report that "the compressible subsonic and supersonic flows of a viscous medium between rotating discs are being investigated for changeable volume flows and directions. In particular solutions of the Navier-Stokes equations and the energy equation together with the empirical law of material constants have been found. The conductivity, viscosity and density of the medium are considered to be temperature dependent and the density is also assumed to be pressure dependent. The theoretical results will later be experimentally verified". Two references are given[8.36a&b].

Finally Farcy and his co-workers at CEAT, Poitiers (item 8.34), report, for their investigation of the transonic flow in an air intake at a large angle of attack, that hot wire and unsteady pressure measurements have been made together with instability investigations using high speed strioscopic visualisation. The results are currently being analysed with emphasis on the different scales of turbulence. Two references are given[8.34a&b].

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8.20a	K. Bühler H. Oerteljr	Berechnung der konvektion im rotierenden behälter. Zamm 1980 (GAMM-Tagunsheft)
8.21a	R.D. Mehta P. Bradshaw	Design rules for small low speed wind tunnels. The Aeronautical Journal, 83, 443 (1979)

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8.33a	M. Presche K.O. Felsch	Experimental investigations of pressure loss in rotating curved rectangular channels. To be published in Archives of Mechanics
8.34a	Ph Thiebaut P. Ardonceau R. Leblanc R. Goethals	First measurements in highly separated transonic flow. Mech Res Communications Vol 6(2), 113, 114 (1979)
8.34b	A. Farcy V. Mercier R. Leblanc R. Goethals	Ecoulement transsonique fortement décollé. 16e Colloque d'Aerodynamique Appliquee, Lille 13-14 et 15 November 1979
8.36a	K.O. Felsch M. Piesche	Berechnung der Spaltströmung in einer Reibungspumpe bei temperaturabhängiger Viskosität zur Förderung hochviskoser Flüssigkeiten. To be published in Acta Mechanica (1980)
8.36b	K.O. Felsch M. Piesche	Ein Beitrag zur Berechnung der Strömung in einer Tesla-Turbine bei temperaturabhängiger Zähigkeit des Fördermediums. To be published in Ingenieur-Archiv (1980)
8.38a	H.H. Frühauf J. Hiebel O. Schäfer C. Umejiaku	Transschall- und Uberschallverdichter. Sonderforschungsbereich 80, Universität Stuttgart Arbeits- und Ergebnisbericht 1977-78-79 (1979)
8.39a	R. Schilling R. Simon	Berechnung der ausgebildeten Strömung in gekrümmten Kanälen mit rechteckigem Querschnitt. Recent developments in theoretical an experimental fluid mechanics, ed U. Muller et al, Springer Verlag (1979)
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8.40b	F.H. Bark P.S. Meijer	Some properties of $E^{1/3}$ layers in a rapidly rotating gas. Proc Second Workshop on gases in strong rotation, Centre d'Etudes Nucleaires de Saclay France, Ed Soubbaramayer (1977)
8.40c	F.H. Bark P.S. Meijer H.I. Cohen	Spin up of a rapdily rotating gas. Phys Fluids 87, 321 (1978)
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8.40f	L.H. Hultgren P.S. Meijer F.H. Bark	On axisymmetric time-dependent source flows in a rapidly rotating gas. To be published in J de Mecanique
8.40g	F.H. Bark P.S. Meijer	On thick Stewartson layers in rapidly rotating gases. Proc third workshop on gases in strong rotation, Comitato Nazionale Energia Nucleare, Rome, Italy, Ed G.B. Scuricini (1979)

9 SHOCKWAVE BOUNDARY LAYER INTERACTIONS
Editor: P.D. Smith

No reports have been received for items 9.11 and 9.16. Items 9.1 and 9.20 have been completed and will be deleted next year. Item 9.21 has been transferred to section 10 and become item 10.39.

There are two new items this year, 9.23 and 9.24. In the first of these Squire at the University of Cambridge is studying shockwave boundary layer interactions at transonic speeds in a number of ways. (i) an integral method has been developed to predict the boundary layer thickness and shape downstream of the interaction, the results are in good agreement with existing measurements. (ii) measurements have been made in the interaction region on an aerofoil at high subsonic speeds and on the tunnel side walls. (iii) measurements of the effect of the trailing edge on the interaction have continued.

In the second new item, 9.24, Debieue and Gaviglio of IMST Marseille are developing an analytical method to describe the Reynolds stress development through a shockwave and are studying the validity in this non-equilibrium flow of the classical analogies connecting velocity and thermal fluctuations. An experimental study has been made of a shockwave boundary layer interaction on a compression ramp. The turbulent flow characteristics have been measured upstream and downstream of the shockwave for comparison with the method. Four references are given[9.24a-d].

Sawyer of RAE Bedford (item 9.2) reports that the static pressure measurements he has made in interactions at Mach numbers of 1.3, 1.4 and 1.5 are being analysed and will appear in a report which will include all the mean flow data. A further series of laser Doppler anemometry measurements are planned for November 1980 to investigate the viscous region at $M = 1.3\text{-}1.5$ and to resolve mean velocity measurement difficulties around the separation bubble at $M = 1.5$.

Delery of ONERA (item 9.4) has continued his study of an interaction leading to the formation of a large separation bubble and has used a two colour laser anemometer to give simultaneous measurements of the horizontal and vertical velocity components $(\overline{u}, \overline{v})$, turbulent intensities $(\overline{u'^2, v'^2})$ and shear stress $(-\overline{u'v'})$. The results confirm those previously obtained with a single component laser and are more reliable and precise. Delery has also established experimentally a limit for shock induced separation in terms of the incompressible shape parameter at the start of the interaction. The experiments were performed in the T2 transonic wind tunnel on a large chord (400 mm) aerofoil mounted near the lower wall of the transonic channel. The limit was defined using various criteria (oil flow, wall pressure distribution and boundary layer probing). A theoretical separation criterion has also been proposed which agrees well with experiment. It uses an empirical correlation for the interaction length and an inverse boundary layer calculation method. Delery has also started an investigation of unsteady effects upon the interaction. An oscillation of the shock is produced by a periodic variation (100-1000 Hz) of the downstream throat of the transonic channel. A Ref 9.4a is given.

Leblanc and co-workers at CEAT Poitiers are investigating both normal shockwave (item 9.8) and oblique shockwave (item 9.14) boundary layer interactions. For the normal

shockwave they are performing an experiment in the S1 transonic wind tunnel at the VKI using both pitot traverses and laser anemometry. It is hoped to compute this flow. For the oblique shockwave experimental work has been delayed but the laminar transitional and turbulent boundary layer including the effects of mass transfer have been computed by a finite difference method. A reference is given[9.8a].

Squire at Cambridge University (item 9.9) has completed his work on the flow at a compression corner downstream of injection and is preparing it for publication. The results confirm the earlier results of Squire and Smith[9.9c], and are being used to extend existing correlations for interaction length and conditions for incipient separation. Three references are given[9.9a-c].

Stanewsky of DFVLR, Gottingen (item 9.13), has published some representative results from his two-dimensional boundary layer measurements[9.13] and is preparing the rest for publication. He has also developed a computational procedure for viscous transonic aerofoil flow in which an analytical solution for the near-normal shock boundary layer interaction is imbedded within a boundary layer/inviscid interactive computation[9.13b]. Stanewsky has also completed the design of two sheared wing models for the investigation of three-dimensional shockwave boundary layer interactions which will be tested in the 1m x 1m DFVLR-AVA transonic wind tunnel.

Zierep of the University of Karlsruhe (item 9.17) has continued his investigations of normal shockwave turbulent boundary layer interactions on curved walls. His analysis results from dividing the flow into three layers. (i) A viscous layer near the wall with pressure induced from above. (ii) A frictionless, compressible shear layer. (iii) A frictionless compressible transonic potential flow. This analysis contains the thickness of the viscous sub-layer as a parameter. A relation between this thickness parameter, the Reynolds number and the shape factor of the undisturbed velcity profile is given in Ref 9.17a. This relation is based upon the fact that the gradient of the wall shear stress in the flow direction at the shock position shows a characteristic behaviour when the thickness parameter is varied. This analysis has now been independently confirmed by an analysis based upon the method of matched asymptotic expansions. The inner expansion which follows from the solution of the compressible disturbance equations near the wall and the outer expansion of the frictionless shear layer show good agreement in asymptotic behaviour both near the wall and at the edge of the boundary layer. An estimate of the order of magnitude in the disturbance equations leads to a general analytic expression for the thickness of the viscous sub-layer[9.17b] which contains the relation derived in Ref 9.17a as a special case. Zierep has also conducted experiments in a supersonic wind tunnel to check his predictions. Curved walls at the top and bottom of a two-dimensional test section were used to produce a stationary shockwave. The flow field in the interaction region was visualised with a differential Mach-Zehnder interferometer. The measured flow structure showed good agreement with the theoretical predictions.

Schmidt of the University of Karlsruhe (item 9.18), has completed his investigation of the shock structure close to the wall in pure gases (agron and nitrogen). The results show that:

(a) The measured density rise very close to the wall reaches, contrary to the results of the simulation calculations with full accommodation at the wall, a maximum of about $M_s = 6$. This can be explained with a decreasing wall accommodation at increasing shock strength, or what is the same, with increasing gradients in gas velocity and temperature.

(b) Close to the wall, where the flow is most sensitive to the intermolecular potential the Lennard-Jones 12-6 potential comes closest to the experimental results over the whole range of the investigated shock strength ($2.24 < M_s < 9.21$).

(c) PVC and glass surfaces produce a lower density rise close to the wall than the usually used aluminium surfaces. This can be attributed to the much lower heat conduction of PVC and glass compared to aluminium.

(d) The density profiles in nitrogen are very similar to those in argon although the density rise is somewhat less than in argon. This allows the conclusion that the rotational modes relax as fast as the translational ones for nitrogen.

(e) The programme for the simulation calculation of the shock structure close to a wall in a binary gas mixture is still erroneous. The temperature does not relax to one equilibrium value for both species in the almost undisturbed part behind the shockwave.

(f) The experimental set up for measuring the partial density in gases by using the electron beam luminiscence method is in the stage that calibration runs can be started.

Finally in item 9.22 Ardonceau of CEAT Poitiers has computed supersonic shockwave turbulent boundary layer interactions with a finite difference method. The boundary layer is computed in the inverse mode in separated regions and an efficient algorithm has been introduced to speed the convergence of the matched viscous-inviscid solution. As a result only about 15 matching iterations are necessary. The emphasis of the work is now on turbulence modelling. Two references[9.22a&b] are given.

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9.13b	M. Nandanan E. Stanewsky G.R. Inger	A computational procedure for transonic airfoil flow including a special solution for shock boundary layer interaction. AIAA 13th Fluid and Plasma Dynamics Meeting, Paper 80-1389
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9.24c	J.F. Debieve A. Borel	Interaction Onde de choc ecoulement cisaille. ONERA RT 19/1455 AN
9.24a	J.F. Debieve H. Gouin J. Gaviglio	Momentum and temperature fluxes in a shockwave-turbulence interaction. IUTAM Symposium Dubrovnik, October 1980

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10 SEPARATION AND REATTACHMENT

Editor: T.K. Fanneløp

The research jobs discussed under the present heading differ widely in scope, character and method. It is difficult to classify the items into definite categories or groups or to discern trends. But the new jobs are always of interest as an indication of new areas of importance or the continued relevance of existing problem areas. We have in all five new jobs this year: three reported for the first time and two transferred from other sections.

Horton, Queen Mary College, London, has initiated a new two-dimensional study of low speed turbulent flow (item 10.36). The purpose and method as outlined on the job card follows:

"An experimental investigation has been started which aims to obtain detailed information on the mean flow and turbulence structure of a two-dimensional separated region with reattachment. The separation and subsequent reattachment of a thick tunnel-floor boundary layer will be induced by means of a shaped double ceiling, with suitable control of the side-wall boundary layers to obtain adequate two-dimensionality. Measurements will be made with pulsed wire and split film anemometers, in addition to conventional probes. A parallel theoretical programme will be made aimed at establishing improved turbulence models for separated flows."

Thiede and Dargel of VFW-Fokker (Bremen) have for some time pursued a study of two-dimensional separated flow regions on the basis of boundary layer theory. This study was announced last year but too late to be included in the annual report. It is reported here as our new item (10.37). For the prediction of two-dimensional compressible laminar and turbulent boundary layers, an inverse integral method is developed, where the surface pressure is defined as a dependent variable with either a prescribed displacement thickness or streamline angle at the boundary layer edge. A matching procedure for two-dimensional separated subsonic and transonic flows has been developed by coupling the inverse boundary layer method with a direct potential flow method in an iterative loop. It is further intended to extend a viscous-transonic airfoil flow prediction method to strong shockwave/boundary layer interactions by (i) experimental consolidation of the inverse boundary layer method and (ii) incorporation of shock-induced separation bubbles in the prediction method. At the time of reporting this year certain improvements in the inverse boundary layer method has been made. This programme of research has been underway for 5-6 years and a number of publications are available[10.37a-h].

Recent developments in a study previously reported as item 15.10, suggest that it should be included in the present section. Henceforth the research by Krause and Hewedy, Aerodynamisches Institut, (Aachen) will be our new item (10.38). The topic of interest is turbulent separation through upstream injection. It is reported that Hewedy has finished his work which included measured pressure distributions on the wall upstream of a wall jet, directed against the flow, also shear stress distributions, velocity profiles and comparison of predicted and measured separation points. The velocity profiles were measured with a pulsed wire anemometer. One new publication is available[10.38a].

The second job transferred from another section belongs to Le Balleur, ONERA, Chatillon, and is now our new item (10.39). It was previously listed as item 9.21. There was 'no progress' reported on item 9.21 last year, primarily because of a change in objective and direction. The new title reflects the change. The emphasis is now on two-dimensional strong viscous-inviscid interactions including separation, shockwaves, trailing edge effects and wakes. The goal of the theoretical effort is now to provide prediction methods for general viscous flow fields (where one or several strong interaction effects may be present) in a way which represents an alternative to a full Navier-Stokes compressible solver. The work includes: adaptation of the inviscid techniques, development of viscous claculations including reverse flow (presently integral methods, direct or inverse), analysis of suitable matching theories (approximations higher than Prandtl's), development of numerical methods to achieve strictly a strong viscid-inviscid coupling (fully stable and automatised). Numerically, this item is related to steady iterative or relaxation techniques. As previously reported, a general coupling algorithm has been developed, with a stabilised direct technique for attached viscous layers, and a new semi-inverse method for separated flows. At the present time, the results include separated bubbles, shockwave boundary layer interactions (supersonic compression ramps, laminar and turbulent), symmetrical supercritical airfoils, with a small perturbation transonic code), trailing-edge and wake interactions (with or without separated bubble). Recent progress focuses on the transonic airfoil problem, with separation bubbles, using a full potential inviscid code. This prediction method now deals with laminar-turbulent calculation, transition criteria, calculation of wake geometry and trailing-edge separation. Effort is made to account for the wake asymmetry and the stalled flows. Effort is also needed for supercritical airfoils, to capture the strong viscous interaction near shockwaves, within its very small scale. An adaption of the method to multi-elements airfoils, at low speed, is investigated with a new inviscid panel method. Two papers have been published based on this work[10.39a&b].

Several of the continuing items are concerned with separation bubbles. At Delft University of Technology, van Ingen (item 10.1), has for some years been investigating laminar separation bubbles and predictions in two-dimensional flows. Following a year of inactivity, it is now planned to start a new experimental programme. Details of the separating flow will be measured using laser-Doppler- anemometry. Veldman of NLR, Amsterdam (item 10.32), has joined forces with Dijkstra of Twente University (item 10.30). One result is a joint publication[10.32a] (alternatively Ref 10.30a). The study is also related to work under item 7.25. Veldman reports that the quasi-simultaneous numerical technique to calculate the viscid-inviscid interaction has recently been combined with an integral approach (based on the Falkner-Skan family of similar profiles) to describe the boundary layer instead of the more accurate finite-difference approach used thus far. In this way it appeared possible to calculate relatively large recirculating eddies, which are much thicker than the oncoming boundary layer. Some further details are supplied by Dijkstra reporting on item 10.30. The method used for the Stewartson-Messiter triple deck problem can give converged results in 10-15 global iteration cycles even for cases where extended separation bubbles are present. Results are now available for both

forward and backward facing steps. The final problem to which the method will be applied are flows over a small hump or a trough in a flat plate.

A rather unique method of generating axi-symmetric separation bubbles was reported last year by Sutton, Cambridge University (item 10.35). A paper by Sutton, McGuinness and Evans is being prepared. It will cover the more important overall effects of periodic excitation on the separation bubble, as described in M.D. McGuinness PhD dissertation[10.35a]. Work has begun using the same axisymmetric apparatus and in the same Reynolds number range on:

(a) the effect of imposing a strong negative pressure gradient in the reattachment region, and

(b) the effect of shortening the reattachment surface (ie shortening the pipe) progressively until there is no reattachment of the time-mean flow.

Flow visualisation studies of a turbulent shear layer near reattachment using a large smoke wind tunnel have continued.

Horton, Queen Mary College, London (item 10.23), has extended the inverse procedure for two-dimensional laminar boundary layer computation with given displacement thickness, to the infinite yawed wing case, including separated flows. Using a measured chordwise displacement thickness, good agreement between computed chordwise and spanwise velocity profiles and surface pressures is obtained. The derived crossflow profiles are in good qualitative agreement with the measurements and, in view of the sensitivity of the measurements to small errors in flow direction, the quantitative agreement is also considered quite good. This work is being prepared for publication.

The separation study of Ha Minh, Chassaing and Martinez of IMF, Toulouse (item 10.33), has produced several publications[10.33a-e] but no further information has been received.

Three items deal, in one way or another, with free vortex flows. Young, Queen Mary College, London (item 10.3), reports that the work on the flow ahead of round nosed cylindrical shape is now completed. It reveals in some detail, by means of velocity and pressure measurements, two main reversed flow vortices wrapping themselves around the cylinder nose and then trailing downstream with small counter-rotating vortices between them and deep in the junction. By far the stronger of the reversed flow vortices is the downstream one. Lateral velocities in these vortices are large and readily become comparable to the undisturbed free stream velocity. The flow pattern is not dissimilar from that reported by other workers for laminar boundary layers with a similar set-up except that the extent of vortices normal to the plate surface is a smaller fraction of the boundary layer thickness with the boundary layer turbulent. The flow is generally well-ordered by comparison with two-dimensional separated flow. A report is in preparation.

Under item 10.24, Bippes, DFVLR, Göttingen, reports that the separation and the development of vortex sheets on an inclined tangent-ogive body with 15 calibres in length has been investigated visually in the water towing tank of the DFVLR. The angles of

attack, are varied up to 90^{0} so that the vortex separation can be studied in its different states, from the stable formation of a pair of symmetric vortices up to the alternating vortex shedding process which is analogous to the development behind an impulsively started cylinder in cross-flow. In order to get some ideas of the dependence of the flow pattern on the oncoming flow conditions, the Reynolds number (based on the diameter of the cylindrical afterbody) is varied between $Re = 5 \times 10^3$ and $Re = 10^5$. One paper has been published[10.24a].

The third study dealing with vortex flows is being undertaken by Mirande and Le Balleur, ONERA, Chatillon (item 10.21). A general study of rolling vortex sheet reattachment is in progress using two different configurations. The first considers reattachment behind a swept step of varying height. Turbulence measurements by hot-wire probes are obtained in and behind the vortex. The second part, which investigates the flow field on the upper side of a swept wing with rounded leading edge, will include a detailed study of the zone of vortex formation. This study is now made on a larger wing with classical measuring techniques. (Surface pressure measurements, oil flow visualisations and probing of the velocity field by directional pressure probes.)

Rodi, University of Karlsruhe (item 10.34), is developing methods to calculate turbulent flows with recirculation (two-dimensional and axisymmetric). The report on the testing of various finite difference schemes[10.34a (1979)] will appear shortly in Computer Methods in Applied Mechanics and Engineering. The application of the upwind differencing scheme, the skew-upwind differencing and the quadratic interpolation schemes to turbulent annular and plane twin jets has been completed and is reported in Ref 10.34a. The conclusion is that the hybrid upwind/central differencing scheme must be considered highly deficient in simulating unconfined recirculating flows and it is unusable for testing the turbulence model performance. The skew-upwind and the quadratic upstream-weighted differencing schemes appear to perform well for the annular and twin jet situations considered. The standard $K-\varepsilon$ turbulence model was found to yield unsatisfactory results, while both the streamline curvature correction and the use of the refined ε-equation suggested by Hanjalić and Launder (ASME Symp Turb Bound Layers, Niagara Falls, 1979) yield reasonably good agreement with the experiments. The report on the calculations in curved mixing layers[10.34b (1979)] was extended significantly and will appear shortly in the J of Fluid Mechanics. A new code is at present being developed for unsteady two-dimensional recirculating flows, and this work is reported as a separate job in the section 'Solution of the complete Navier-Stokes equations'.

Items 10.11, 10.12 and 10.29 dealing with flows near and in the base region of slender missile shaped bodies, are closely related. Agrell, FFA, Stockholm, has replaced White and Nyberg as prime investigator and contact. Item 10.11 and 10.29 dealing with boat-tail flow separation without and with a propulsive (simulated) jet, have been completed at least for the experimental part. The programme consisted of pressure measurements on conical afterbodies of a wind tunnel model at supersonic Mach numbers. The separation on the afterbody was created by injection of high pressure air through a jet nozzle in the base area of the model. The investigation was also made at angles of attack.

The final report will be published later but the viewgraphs presented at DGLR-Symposium, Strömungen mit Ablösung, Munich, 19-20 September 1979 have been issued[10.11a]. On item 10.12 it is reported that no progress has been made on this item during the period, but the report of probe measurements of the velocity profile in a separaced region on a conical afterbody has been issued[10.12a]. Likewise a paper has been published dealing with the problems of particle generation encountered when trying to measure in the same separated region with laser-Doppler-velocimetry[10.12b].

Agrell, FFA, Stockholm, also reports a new item (10.40) dealing with a related problem. Here a new wind tunnel investigation has been started to measure the forces on control fins. The fins are located on the afterbody and exposed to both separated and non-separated flow depending on the pressure ratio of the air-jet nozzle placed in the base plane of the model. The tests are run at both subsonic and supersonic Mach numbers with variation of angles of attack at different jet pressure ratios and control angles.

The remaining active items in this section report little or no progress this year. This is true for items 10.8 and 10.22 (no progress) whereas one paper is being prepared for publication under item 10.7. Item 10.26 is considered completed and no further work is planned. With, in all, five new items, the work in the present section has grown considerably in the last year.

REFERENCES

No.	Author	Title, etc
10.11a	J. Agrell	Experimental investigation of flow separation on afterbodies with a centred propulsive jet and supersonic external flow at small angles of attack. DGLR-Symposium in Strömungen mit Ablösung, Munich, 19-20 September 1979, FFAP-A-455
10.12a	J. Agrell	An experimental survey of a separated region on a conical afterbody in a supersonic free stream. FFA TN AU-1187 (1978)
10.12b	J. Agrell L. Danielsson	On the application of laser-Doppler-velocimetry to the measurement of velocities in large separated regions bounded by superonic flows (1980)
10.24a	H. Rippes A. Maier	Sichtbarmachung der Ablösung von Wirbelschichten an schlanken Flügeln und Rumpfkörpern. DGLR-Jahrbuch (1979)

REFERENCES (continued)

No.	Author	Title, etc
10.30a	A.E.P. Veldman D. Dijkstra	A fast method to solve incompressible boundary layer interaction problems. Proceedings 7th International Conference on Numerical Methods in Fluid Dynamics, Stanford (1980)
10.32a	A.E.P. Veldman D. Dijkstra	A fast method to solve incompressible boundary layer interaction problems. Proceedings 7th International Conference on Numerical Methods in Fluid Dynamics, Stanford (1980)
10.33a	G. Martinez H. Boisson H. Ha Minh	Vortex shedding from circular cylinders. A numerical simulation, EUROMECH Colloquium 119, London, July 1979
10.33b	G. Martinez H. Boisson	Etude numérique et expérimentale de la convection forcée autour d'un cylindr circulaire en régime instationnaire. 4e Congrés Francais de Mécanique, Nancy, September 1979
10.33c	H. Ha Minh H. Boisson G. Martinez	Unsteady mixed convection heat transfer around a circular cylinder. Annual meeting of the ASME Heat Transfer Division, Chicago, November 1980
10.33d	M. Braza H. Ha Minh H. Boisson	Ecoulement décollé instationnaire derriere des obstacles. EUROMECH Colloquium 135, Marseille, Octobre 1980
10.33e	H. Boisson A. Sevrain M. Braza	Statistiques sur les durées des épisodes turbulents au passage des tour-billions émis par un cylindre. EUROMECH Colloquium 132, Lyon, July 1980
10.34a	M.A. Leschziner W. Rodi	Calculation of annular and twin parallel jets using various discretisation schemes and turbulence model variants. Rept SFB 80/T/159, Universität Karlsruhe, February 1980
10.35a	M.D. McGuinness	Flow with a separation bubble; steady and unsteady aspects. Cambridge University, PhD Dissertation, June 1978
10.37a	P. Thiede G. Dargel	Berechnung abgelöster turbulenter Grenzschichten bei transsonischer Profilströmung. ZTL FAG 4 Abschlussbericht 4.03/7/75, VFW-Fokker (1975)
10.37b	P. Thiede G. Dargel	Berechnung abgelöster transsonischer Profilstromungen. ZTL FAG 4 Abschlussbereicht 4103/8/76, VFW-Fokker (1976)

The final report will be published later but the viewgraphs presented at DGLR-Symposium, Strömungen mit Ablösung, Munich, 19-20 September 1979 have been issued[10.11a]. On item 10.12 it is reported that no progress has been made on this item during the period, but the report of probe measurements of the velocity profile in a separated region on a conical afterbody has been issued[10.12a]. Likewise a paper has been published dealing with the problems of particle generation encountered when trying to measure in the same separated region with laser-Doppler-velocimetry[10.12b].

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10.12a	J. Agrell	An experimental survey of a separated region on a conical afterbody in a supersonic free stream. FFA TN AU-1187 (1978)
10.12b	J. Agrell L. Danielsson	On the application of laser-Doppler-velocimetry to the measurement of velocities in large separated regions bounded by superonic flows (1980)
10.24a	H. Bippes A. Maier	Sichtbarmachung der Ablösung von Wirbelschichten an schlanken Flügeln und Rumpfkörpern. DGLR-Jahrbuch (1979)

REFERENCES (concluded)

No.	Author	Title, etc
10.37c	P. Thiede	Prediction method for steady aerodynamic loading on air-foils with separated transonic flow. AGARD-CP-204 (1976)
10.37d	G. Dargel	Verbesserung eines Rechenverfahrens fur Klappenprofile mit Grenzschichtablosung - Inverses Integralverfahren zur Berechnung abgeloster und anliegender laminarer Grenzschichten. VFW-Fokker, Bericht 671/77 (1977)
10.37e	P. Thiede	Extension of the boundary layer concept to the calculation of two-dimensional separated flows. DEA-meeting 'Viscous and Interacting Flow Field Effects', Gottingen (1977)
10.37f	P. Thiede	Ein inverses Integralverfahren zur Berechnung abgeloster turbulenter Grenzschichten. DLR-FB 77-16 (1977)
10.37g	P. Thiede	Beitrag zur Berechnung abgeloster unter- und uberkritischer Profilstromungen. 19 Jahrestagung der DGLR, Berlin (1977)
10.37h	P. Thiede	Berechnung two-dimensional abgeloster Stromungsbereiche auf der Basis des Grenzschichtkonzepts. DGLR-Symposium 'Stromungen mit Ablosung', Munchen (1979)
10.38	N.I.I Hewedy	Wanddruck- und Wandschubspannungs- verteilung eines tan-gential ausgeblasenen Gegenstroms. Abhandlungen des AIA, Heft 24, pp 44-49, 1979 (see also Heft 25, pp 64-65
10.39a	J.C. Le Balleur H. Viviand	Methode de calcul des ecoulements decolles bidimensionnals aux grands nombres de Reynolds. 16 eme Colloque AAAF (Lille) - TP, ONERA No.1979-145
10.39b	J.C. Le Balleur R. Peyret H. Viviand	Numerical studies in high Reynolds number aerodynamics. Symposium on Computers in Aerodynamics (Farmingdale, June 1979) - Computers and Fluids, Vol.8, No.1, pp 1-30 (1980)

11 FREE SHEAR LAYERS AND JETS

Editor: J. Cousteix

Several studies described in this Section are now complete (11.2, 11.3, 11.15). Item 11.3, Dier-Devillers, CNRS concerned with the penetration of a transverse jet in a hypersonic flow is completed by a thesis by J.F. Devillers[11.3a].

Item 11.10 is now deleted.

A new entry is item 11.21, Gersten, Ruhr Universität. It deals with an application of higher order boundary layer theory to the investigation of nonisothermal laminar and turbulent plane free jet flows. Effects of buoyancy forces and streamline curvature as functions of initial jet orientation have been studied theoretically[11.21a].

Chassaing, Ha Minh, Boisson (item 11.18) have been studying the turbulent mixing of two non reacting gases (CO_2 and Air) experimentally and theoretically. A thesis by Chassaing has been issued[11.18b]. Another publication is also available[11.18a].

The calculations of swirling jets reported by Rodi (item 11.19), Universität Karlsruhe, continue at a low pace and no new results are described. More work has been done however, on item 11.20 by Rodi. A report (given in the 1979 EUROVISC Report under Ref 11.20a) on a locally elliptic calculation procedure for three-dimensional flows will be published shortly in the Computer Methods in Applied Mechanics and Engineering. The application of the method to other test cases, mainly with higher ratio of jet to cross flow velocity continues. Flow visualisation studies of a jet in a cross flow have been completed and are reported in Ref 11.20a. They show completely different behaviour of the flow for velocity ratios below 0.4 and above 0.6. In the former case the cross flow acts like a half-opened lid and bends round the jet very quickly, in the latter case the jet penetrates into the cross flow and a very complex flow pattern is set up. Hot wire measurements in the jet in a cross flow are in progress, and first results are reported in Ref 11.20b, and cover the flow inside the jet pipe where the non-uniformity of the velocity profiles extends up to three pipe diameters upstream for small velocity ratios. Measurements in a slightly heated jet have also been initiated and it is planned to use the conditional sampling technique of Hudreopoulos and Bradshaw (described in the 1979 EUROVISC Report[4.14a]).

At University of Manchester, the work reported by Johannesen (item 11.7) on the mixing of jets from nozzles with and without notches issuing into a coflowing stream is continuing. As in previous years no further information is given.

The experimental work described by Leuchter (item 11.11), ONERA is in progress. Several configurations of turbulent jet mixing layer flows have been investigated including the effects of initial turbulence. The behaviour of the length and time scales and the development of the large coherent structures have been analysed. The longitudinal and transverse length scales have been deduced from space correlation functions obtained with two distinct hot wires, whereas the time-scales are deduced from auto-correlation functions. Comparison between these two types of scales (via the Taylor hypothesis) shows agreement only in a narrow region of the jet mixing layers. The large scale coherent structures are currently characterised by means of a technique of conditional sampling

using two hot wires. The relative energy content, the characteristic frequency and the convection velocity of these structures have been studied under various flow conditions. Other activities have included the analysis of the turbulence of a scalar in a slightly heated jet and to that of the fluctuating pressure field in an isothermal jet.

REFERENCES

No.	Author	Title, etc
11.3a	J.F. Devillers	Étude et optimisation d'une injection secondaire bidimen-sionnelle en ecoulement supersonique. These de Doctorat d'Etat (à paraître) (1979)
11.18a	H. Ha Minh P. Chassaing	Diffusion turbulente isotherme en milieu à masse volumique variable composé de deux gaz non réactifs. Rapport ATP, Avril 79
11.18b	P. Chassaing	Mélange turbulent de gaz inertes dans un jet de tube libre. Thèse de Doctorate d'Etat ès-Science, 13 Décembre 1979
11.20a	J.F. Foss	Flow visualisation studies in a cross flow. Report SFB 80/T/161, University of Karlsruhe (1980)
11.20b	J. Andreopoulos	Measurements in a pipe flow issuing perpendicularly into a cross stream. University of Karlsruhe, Report SFB 80 in preparation 1980
11.21a	K. Gersten S. Schilawa F.K. v Schulz-Hausmann	Nichtisotherme ebene Freistrahlen unter Schwerkrafteinfluss.

12 HEAT TRANSFER
Editor: J. Cousteix

Two items are new. Item 12.15 deals with the flow of humid air over cold surfaces for studying the performance of heat exchanges. Item 12.16 is related to the prediction of turbulent Prandtl and Schmidt numbers from modelled transport equations. No response has been obtained for item 12.14.

Horton (item 12.3) Queen Mary College, reports work on the study of the skin friction and heat transfer at supersonic speeds. Difficulties have been encountered due to problems of tunnel blockage, but further work will be carried out when this problem is overcome.

At DFVLR, Göttingen, Dankert-Legge-Koppenwallner (item 12.8), experimental work is done on measurements of the drag, the Stanton number and the recovery factor of sharp cones in a free jet wind tunnel with helium, nitrogen and air as test gases in the free molecular and transition regime. The influence of the wall temperature on the drag at complete accommodation and the influence of incomplete accommodation on the aerodynamic coefficients have been studied at a variety of flow conditions. The lowest accommodation coefficient for energy transfer is 0.25 for helium at 300 K on a gold cone at 800 K. The heat transfer is reduced significantly also in the transition regime. An influence of the accommodation on the recovery temperature has not been detected. This work is done in cooperation with the firm DORNIER, Friedichshafen/Bodensee.

The experimental investigation reported by Frössling, University of Gothenburg, item 12.10, of the process of conjugated heat transfer from two wedge-shaped extended surfaces (of iron and copper) is finished. Some of the experimental results have then been used for testing the method of calculation previously developed. Good agreement between experimental and calculated quantities was found.

The new item 12.15, Dixon, University of Liverpool, describes an experimental and theoretical investigation on the heat/mass transfer and flow phenomena which occur when hot, humid air (35-70°C) impinges at various velocities onto cold surfaces. Interest is focussed on the performance of continuous fin/tube heat exchangers, single fins and also water entrainment by the air flow past the condensing water. A humid air tunnel has been designed and its construction is nearly complete. Testing of the basic tunnel performance is due to commence in the summer of 1980 and provided no problems of a serious nature arise testing of basic fins will be started immediately after this.

Work reported by Jischa, (item 12.16) University of Essen is described in the new item 12.16. This work has been in progress for sometime and four publications are given 12, 16a-d. The transport equations for the Reynolds fluxes of momentum, heat and mass give information about the turbulent Prandtl and Schmidt number as a function of the molecular Prandtl and Schmidt number, the Reynolds number and position in the flow field. This has been shown at first for fully developed tube and channel flow. The heat and mass flux, the Nusselt and Sherwood numbers, can be determined in principle without further empirical information.

REFERENCES

No.	Author	Title, etc
12.16a	M. Jischa H.B. Rieke	Turbulent heat transfer in duct flow. Proc of 6th Intern Heat Transfer Conference, Toronto 1978, Vol II FC (a) - 10
12.16b	M. Jischa H.B. Rieke	About the turbulent Prandtl number in liquid metal duct flow. Proc of Turbulent Forced Convection in Channels and Rod Bundels, Istanbul (1978)
12.16c	M. Jischa H.B. Rieke	On the influence of the molecular Prandtl number on the turbulent Prandtl number: recent developments in theoretical and experimental fluid mechanics. Eds: U.V. Müller, K.G. Roesner, B. Schmidt, Spring-Verlag Berlin, pp 457-466 (1979)
12.16d	M. Jischa H.B. Rieke	About the prediction of turbulent Prandtl and Schmidt numbers from modelled transport equations. Int J Heat Mass Transfer 22, pp 1547-1555 (1979)

13 MASS TRANSFER AND BOUNDARY LAYER CONTROL
Editor: J. Cousteix

Three items are deleted in the present section (items 13.2, 13.4, 13.5). Item 13.3 is transferred to Section 4 and the corresponding work is described in item 4.11.

At University of Oxford, Schultz (item 13.6) a cascade has been used for aerodynamic and heat transfer studies on a range of nozzle guide vanes and rotor blades. The holographic technique has been improved by the use of a white light reconstruction method. A rapid acting wake traverse mechanism has been developed and used for loss coefficient studies on a series of high performance turbine blades. A new internal heat transfer rig has been made using phase change paints for the measurements of surface temperatures. This rig will use a 10 x full scale model of the internal passages of a turbine blade. A new tandem ejector driven blowdown cascade is approaching completion.

Lasek (item 13.11) CNRS Meudon, indicates that experiments on the propagation of thermal perturbations in a tangential jet are in progress.

The experiments carried out at University of Buchum, Gersten (item 13.14) are to investigate the effect of combined injection and suction on incompressible laminar flow around porous cylinders, particularly with large mass transfer rates. Measurements of pressure distribution and wake characteristics have been performed. An investigation of turbulence in a detached shear layer (ie blown-off boundary layer) is planned.

The work reported by Durst, Kleine, Rastogi (item 13.15) University of Karlsruhe on the influence of high polymer additives on laminar as well as turbulent fluid flow has been described at length in the 1979 EUROVISC report. Work is being continued.

Two new items (13.16, 13.17) from Thiede, VFW-Fokker GmbH, are given in the present report. However the study is not new and began several years ago. Item 13.16 was first concerned with theoretical investigations of turbulent flow control by a suction slot including an extension of a two-dimensional turbulent boundary layer prediction method for the incorporation of slot suction and an optimisation of the suction rate for the prevention of shock-induced separation. Pressure distribution and boundary layer measurements of a supercritical airfoil at off-design conditions with slot suction in the shock region have been performed. The experimental results confirm the expected buffet onset increase by single slot suction within the shock region on a supercritical airfoil not designed for the special suction requirements. The better the slot positioning with respect to the shock the greater is efficiency. Therefore the installation of a multiple suction slot and modifications of the airfoil contour will be also taken into consideration in the future. Furthermore, the experimental results indicate that the theoretical approach to handle the suction effects requires further refinement. Results of this study are given in Refs 13.16a&b.

The second item from Thiede deals with a theoretical investigation of laminar flow control for friction drag reductions by multiple slot suction on supercritical wings.

It includes:

extension of a two-dimensional laminar boundary layer prediction method to include slot suction,

development of an optimisation strategy for multiple slot suction to keep the number of slots to a minimum,

calculation of off-design suction conditions.

Wind tunnel experiments have also been performed to investigate laminar flow control in the shock region. Investigations for laminar flow control flight tests have also been performed. The current work is on an improvement of a boundary layer integral method with slot suction and on the design of laminar flow control devices for a two-dimensional wind tunnel model at transonic test conditions using boundary layer predictions. An early publication is given[13.17a].

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No.	Author	Title, etc
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13.16b	P. Thiede	Supercritical airfoil flow control by slot suction in the shock region. DEA-Meeting Viscous and Interacting Flow Field Effects, Annapolis, USA (1980)
13.17a	P. Thiede F. Otte	Theoretische Untersuchungen zur Laminarhaltung der kompressiblen Grenzschicht durch Schlitzabsaugung, ZfW 23 (1975)

14 PRESSURE FLUCTUATIONS, AERODYNAMIC NOISE GENERATION AND THE EFFECTS OF FREE STREAM FLUCTUATIONS

Editor: T.K. Fannelφp

The decline research activities under the present heading continues. Aerodynamic noise generation appears to be the only problem area where interest remains high. Cikadi, Bartenwerfer, Barsikow and Neise, DFVLR, Berlin (item 14.17) have for several years investigated noise from centrifugal blowers and other industrial flow components. The most recent report points out that the increase of the blade passage tone of a centrifugal fan as a consequence of the inlet vane control, can be explained by the interaction between the wakes behind the vanes and the rotating impeller blades[14.17a]. The flow field behind a vane control with different pitch angles of the guide vanes has been investigated to give ideas for the noise reduction in practical fan installations with inlet vane control, [14.17b]. By mounting the vane control further upstream from the fan, it is possible to reduce the radiated noise for higher volume flows[14.17c].

At the discharge from an impeller of a centrifugal fan, the instantaneous velocity has been measured by hot wire probes. The impeller was driven first without casing and then enclosed in casings of different sizes and design. It was found that, compared with the 'free' impeller, the casings influence unfavourably the flow inside the impeller. Larger casings do not impair the efficiency, but lead to better aerodynamic fan characteristics and to lower fan noise levels[14.17d&e]. Investigations by means of the so-called 'evolution strategy' trying to optimise the fan casing with respect to low noise radiation, showed similar results[14.17f].

On a study initiated last year (item 14.33) Morfey, (ISVR, Southampton), reports that considerable progress has been made in developing an engineering method to predict non-linear spectral distortion. Some preliminary results are reported in Ref 14.33a, but two additional publications are announced as well[14.33b&c]. A complementary project has been started on non-linear propagation in line flowducts (eg aircraft engine inlet and exhaust). Under item 14.27, Morfey submits that extension of the work previously reported is planned to cover coaxial jets and jets in coflowing streams.

On his study of turbulent jet noise (item 14.18) Grosche, DFVLR Göttingen, informs us that the investigation of density gradient fluctuations in turbulent jets has been interrupted by other urgent tasks, therefore only limited progress has been achieved up to now. It is intended to continue the job as soon as possible along the lines stated in the 1979 progress report. One new publication is available[14.18a].

The effects of wind tunnel noise on transition (item 14.15) has been investigated for the last few years by Ross, NLR (Amsterdam). An instrumented cone, designed for comparative testing in various wind tunnels, has now been tested in the tunnels of NAE, ONERA, FFA and NLR. The results are being analysed. The test cone will be available to other interested institutions in 1981.

On noise research under item 14.22, we have no report this year except that the work continues.

Comte-Bellot and coworkers, ECL (Lyon), report progress on the continuing item (14.19) and also a new job on noise generation (item 14.34). The work under item 14.19 deals with the generation of noise by airfoils in the case of velocity perturbations in the incident flow. The distribution of equivalent acoustic sources on the airfoil surface (in the sense of Lighthill) is obtained by cross-correlating the radiated acoustic pressure and the pressure on the airfoil. For a perturbed incident flow, the contribution of the leading edge region to the emitted noise is very large. Noise prediction expressions are developed by use of a aerodynamic transfer function. Application to rotor noise is in progress. Four new publications are available[14.19a-d].

The new job deals with the noise generated by cold subsonic jets. Of special interest are source location techniques and physical understanding of the mechanisms involved in noise production. In this respect, both clean and excited jets are studied through simultaneous measurements in the aerodynamic field and in the acoustic far field. Work on this topic has been under way for some time and in all 12 publications are available [14.34a-l].

The second problem area with substantial activity is concerned with free stream fluctuations. On item 14.31 Frössling, Sunden and Hanarp of Chalmers University (Gothenburg), informs us that experimental and theoretical studies have been performed concerning the influence of the turbulence structure in the free stream on the velocity boundary layer on a circular cylinder. In the experiments, the cylinder was constructed with a splitter-plate at the rear in order to minimise disturbances from the wake. During the work, the ratio A/D was kept small (<0.1) and the turbulence intensity was in the range of 2.5% < Tu < 11.5%. Both experiments and theoretical calculations showed that the velocity boundary layer for these cases was unaffected by the turbulence in the free stream. Measurements of the turbulence structure in the boundary layer have also been undertaken. These data are now under careful evaluation. Investigations of the influence of the free stream turbulence on the temperature boundary layer will be started shortly. Three new publications are available[14.31a-c].

From Imperial College, (London) (item 14.21) Bradshaw reports that a PhD thesis, including extensive data analysis of free stream turbulence effects and new conditional sampling measurements in a slightly heated boundary layer below a turbulent stream, is now available on microfiche[14.21a]. A short review, based on the thesis, has been written for the 1980-81 Stanford meetings on Complex Turbulent Flows. Under item 14.23 Tensi and Tsen, CEAT (Poitiers), intend to measure the influence of exterior turbulence on the leading edge separation bubble on a NACA 65012 airfoil, but no further information is available. Item 14.20, also concerned with free stream turbulence, will be deleted as no work has been done the last three years. Zdravkovich, University of Salford, has discontinued work under item 14.32, but an additional publication is available[14.32a]. On items 14.24 and 14.29, by Bjørnø, Technical University, Denmark, we know only that the projects continue. One publication is available[14.29a].

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14.17b	B. Barsikow	Lärmminderung durch Abstandsvergrösserung zwischen Laufrad und Drall-regier eines Radialventilators, Teil 1 (Noise reduction by enlarging the distance between the impeller and the inlet vane control of a centrifugal fan, Part 1). DFVLR - IB 251 - 79 B 16 (1979)
14.17c	B. Barsikow	Wie (17.17b), Teil 2 (same as (14.17b), Part 2). DFVLR - IB 251 - 80 B 1 (1980)
14.17d	T. Gikadi	Einfluss der Gehäuseform auf die Kennlinie unde die Geräuscherzeugung eines Radialventilators in: Fortschritte der Akustik. Proceed of DAGA 80, (Munchen) März 11-13 1980
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14.17f	N. Hillebrand W. Neise B. Barsikow	Anwendung der Evolutionsstrategie auf die Formgebung eines Radialventilator gebürses im Hinblick auf geringe Schallerzeugung (Designing a centrifugal fan casing in respect of low noise radiation by means of the evolution strategy.) in: Fortschritte der Akustik, Proceed of DAGA 80 (München) 11-13 März 1980
14.18a	J. Kompenhans	Die Messung von Dichtegradientenschwankungen in Stromungen mit Hilfe des Laser-Schlieren-Kreuzstrahlverfahrens. Vortrag DFVLR-internes Symp Messphysik, Oberpfaffenhofen, 3-5/12-79. Will be available as DFVLR-Mitt 80
14.19a	L. Gaudriot H. Arbey A. Hellion	Far-field technique for analysis of noise-generating mechanism. Technical meeting; source location and active control of noise, Cambridge (1979)
14.19b	H. Arbey M. Sunyach G. Comte-Bellot	Use of adjoint jets to investigate the aerodynamic sound of airfoils at moderately high Reynolds numbers. Journal of Sound and Vibration, 65 (2) (1979)
14.19c	H. Arbey A. Hellion B. Escudie	Application de l'imagerie acoustique a l'emission sonore a frequence discrete d'un profil place en ecoulement sain. 4e Congres Francais de Mecanique, Nancy (1979)

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14.21a	P.E. Hancock	The effects of free stream turbulence on a turbulent boundary layer. PhD thesis, Imperial College
14.29a	S. Gravsholt	Rheological properties of highly dilute viscoelastic aqueous detergent solutions. Proceedings of VIIIth International Congress on Rheology, Naples, September 1980 (in press)
14.31a	B. Sundén	A theoretical investigation of the effect of free stream turbulence on skin friction and heat transfer for a bluff body. Int J Heat and Mass Transfer, 22, 7, 1125-1135 (1979)
14.31b	B. Sundén	Calculation of the influence of free stream turbulence on flow field and heat transfer around a circular cylinder by using a two-equation turbulence model. Publ 79/2, Department of Applied Thermo and Fluid Dynamics, Chalmers University of Technology, Göteborg (1979)
14.31c	L. Hanarp	An investigation of the structure of grid-generated turbulence. Internal report No.80/7, Department of Applied Thermo and Fluid Dynamics, Chalmers University of Technology, Göteborg (1980)
14.32a	M.M. Zdravkovich	Excitation, amplification and suppression of flow-induced vibrations in heat exchanges. Proc Sym on Practical Experiences with Flow-induced Vibrations, Karlsruhe, Germany, 3-6 September 1979
14.33a	C.L. Morfey G.P. Howell	Non linear propagation of aircraft noise in the atmosphere. AIAA Paper 80-1041
14.33b	C.L. Morfey	Non linear propagation of jet noise in the atmosphere. RAE Technical Report 80004 (1980)
14.33c	C.L. Morfey G.P. Howell	Dispersion of sound in atmospheric air. J Acoust Soc Am (in preparation)
14.34a	D. Jure M. Sunyach J. Bataille	Application de la méthode de causalité a l'étude du bruit d'un jet subsonique. CRAS Paris, t 282, série B, P 269-272 (1976)

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14.34c	D. Jure M. Sunyach J. Bataille	Analysis of subsonic jet noise using cross-correlation techniques. 9th International Congress on Acoustics, Madrid (1977)
14.34d	D. Jure M. Sunyach J. Bataille	Recherche des structures turbulentes acoustiquement active dans un jet froid subsonique. 3eme Congres Francais de Mécanique, Grenoble (1977)
14.34e	D. Jure M. Sunyach G. Comte-Bellot	Attenuation d'un faisceau ultrasonore traversant un jet turbulent. Euromech No.94, Marseille (1977)
14.34f	D. Jure M. Sunyach G. Comte-Bellot	Intermittency of noise generation in subsonic jets. Institute of Acoustics Spring Congress, Cambridge (1978)
14.34g	D. Jure	Analyse par une méthode d'intercorrélation de l'émission acoustique moyenne et instantanée d'un jet subsonique. These de Docteur-Ingénieur, Lyon (1978)
14.34h	D. Jure J. Bataille G. Comte-Bellot	Bruit de jets coaxioux froids subsoniques. J. Mécanique Appliquée, Vol 2, No.3, p 385-398 (1978)
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14.34j	D. Jure M. Sunyach	Recherche par échantillonnage conditionnel des structures acoustirement actives dans les jets subsoniques froids. CRASB 287, p 227-229 (1978)
14.34k	D. Jure M. Sunyach G. Comte-Bellot	Filtered azimuthal correlations in the acoustic far field of a subsonic jet. AIAA J 17(1), p 112-113 (1979)
14.34l	D. Jure M. Sunyach	Radiation properties of a turbulent jet excited by a sinusoidal acoustic disturbance. Congres IUTAM, Göttingen (1979)

15 UNSTEADY FLOWS
Editor: W. Kordulla

The number of jobs in this section decreased from 16 to 15 because of the completion of job item 15.4 by Davies and Hardin, USoSV, Southampton. Work is reported to be temporarily interrupted by Krause, THAAI (item 15.9) and Faltinsen, UTNTH (item 15.17). Fernholz, Vagt and Reitebuch, TUB(HFI) (Item 15.18) report that the test section of the wind tunnel had to be rebuilt because of noise and vibration problems, but that its calibration is in progress. Only Refs are given by Maresca, IMF (M), (item 15.22)[15.22a-e]. Thirteen Refs are listed, five of which are due to the same job (item 15.22) versus 15 last year.

Young from the Queen Mary College, London (item 15.1) reports that the effects of oscillating flow in transition are being examined, but that the work has not yet reached the stage where there is material to publish. Gribben from the University of Strathclyde, Glasgow (item 15.2) used an approximation for the main stream flow properties valid for moderate values of the compressibility frequency parameter[15.2a]. He now hopes to expand the solution to higher values of this parameter.

At the University of Aachen Marenbach, Zeller and Krause (item 15.3) report that for free stream Mach number of about 2.1 the flow in the wake of a cylinder in axial flow and of a flat plate in shock-free flow is compared with the wake disturbed by a shock wave. Measurements made with LDA are in progress. At the same place Franke (item 15.11) continues Finke's work, and is carrying out experimental work on sectional airfoil models. Unsteady pressure measurements will be made for large angles of attack (with shock oscillation) and for tangential blowing.

Michel, Cousteix and Houdeville at CERT-DERAT, Toulouse (item 15.14) report on experimental investigations as well as on developments with respect to prediction methods. The investigation of the periodic turbulent boundary layer in an adverse mean pressure gradient was continued with measurements of $\langle u'^2 \rangle$, $\langle v'^2 \rangle$ and $- \langle u'v' \rangle$ profiles using a one-dimensional LDA system.

Three successive data acquisitions with the fringe plan in different positions were made. The results are in rather good agreement with measurements provided by an x-wire probe in regions without periodic reverse flow. The unsteady turbulent boundary layer on a flat plate is being studied for a large range of Strouhal numbers. Measurements are performed with hot-wire anemometry.

It is stated that the three-dimensional integral method for unsteady turbulent boundary layers in slightly compressible flow is now available for practical applications on helicopter blades. Calculations have also been performed by using global equations either in direct or inverse mode with analysis of singularities. The comparison of experimental results with those predicted by an inverse unsteady integral method for configurations with reverse flows are available. A calculation method for configurations with reverse flows are available. A calculation method has been developed to predict turbulent unsteady boundary layers using finite-volume techniques. Different turbulence closure assumptions have been used in comparisons with experimental data. Transport equation

models, taking into account the normal stress terms, are shown to provide results in good agreement with experimental data.

Peube and Peube from LDF, Poitiers (item 15.15), continue their studies by using Laser Doppler anemometry with two colours which allow to obtain two simultaneous components of the velocity and to calculate the 'instantaneous' Reynolds stress. Actually the problem of conditional sampling of data is being examined with care. Hirsh at the Vrije Universiteit of Brussels (item 15.19) reports that dynamic pressure measurements have been made on the surface of an aerofoil, in collaboration with the DFVLR Göttingen. In addition new measurements of turbulent stresses in the wake of the airfoil for several incidences and frequencies were performed[15.19a]. Measurements of the turbulence structure in the wake near dynamic stall regime were included, and compared with the pressure measurements. The velocity and Reynolds stress measurements on the surface of the airfoil will be performed in the near future.

Ehrensperger and Thomann at the ETH, Zurich (item 15.20) indicate that their experiments for unsteady laminar flow clearly show the development of separation. Some detail-problems, however, remain to be solved. At the same place Lommel and Thomann (item 15.21) confirmed transition by means of hot-wire measurements. Its distance from the signal front depends on the applied input-pressure and the observation location. Difficulties with the membrane influence upon signal have to be solved.

Jonsson at the Technical University of Denmark (item 15.23) reports that the wave friction factor for a rippled sand bed has been found as a function of grain size, or ripple height, over amplitude of water particle motion.

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15.2b	R.J. Gribben	Fluctuating flow past a cylinder at high frequencies. App Sci Res, Vol 35, 43-58 (1979)
15.3a	G. Marenbach	Störung turbulenter Mischzonen durch Stobwellen, Abhandlungen aus dem Aerodyn Institut, RWTH Aachen, Heft 25, 1980
15.11a	Th Franke	Stobschwingungen an Profilen in schallnaher. Anströmung, Abhandlungen des AIA, Heft 25, pp 58-59 (1980)
15.14a	J. Cousteix J.C. LeBalleur R. Houdeville	Calcul des couches limites instationnaires en mode direct ou inverse, écoulements de retour inclus - Analyse des singularites. La Recherche Aerospatiale, No.3, Mai 1980

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15.22a	D. Favier J. Rebont C. Maresca	Vortex shedding from a body oscillating in-line in a unidirectional free stream and from a fixed body in oscillating flow. Euromech 113, London, July 1979
15.22b	D. Favier J. Rebont C. Maresca	Profile d'aile à grande incidence en mouvement de pilonnement. 16ième colloque AAAF, Lille, November 1979
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15.22d	D. Favier J. Rebont C. Maresca	Large-amplitude fluctuations of velocity and incidence on oscillating airfoils. AIAA Journal, Vol 17, No.11, November 1979
15.22e	C. Maresca D. Favier J. Rebont Jones Telionis	Measurement and visualisation of a stalling airfoil in translational oscillation. AIAA Paper 79-1519, Williamsburg, July 1979
15.23a	I.G. Jonsson	A new approach to oscillatory rough turbulent boundary layers. Ocean Engng Vol 7, No.1, 109-152 (1980)
15.23b	I.G. Jonsson	Discussion of 'Friction factors for movable sand beds under rough turbulent oscillatory flow' by P. Vitale, J. Waterways, Port, Coastal and Ocean Division, Am Soc Civ Engineers (1980) (to appear)

16 EXCRESCENCES AND ROUGHNESS EFFECTS
Editor: P.D. Smith

In this section the items are all concerned with the effects of surface roughness or excrescences upon boundary layer behaviour. The impetus for much of the work comes from marine applications.

There are three new items this year, 16.13-16.15. In the first of these Krogstad of NTH, Trondheim suggests that the effect of roughness on three-dimensional turbulent boundary layers has received little attention in the literature. To remedy this some preliminary measurements will be performed at NTH during the summer of 1980 on the model described under item 3.32.

In the second new item (item 16.14) Schatzmann and Webel of the University of Karlsruhe have undertaken an experimental programme to investigate the dependence of turbulent diffusion and dispersion on roughness structure in open channel flow. The laboratory experiments include hot film measurements of mean and fluctuating velocities for different aspect ratios, Reynolds numbers and bed roughness structures. Length scales of turbulence are obtained from the correlation coefficients and energy spectra. A reference, 16.14a, is given.

In the final new item (item 16.15) for which two Refs, 16.15a&b are given, Andreopoulos of the University of Karlsruhe is investigating a double step change of surface roughness in a turbulent boundary layer. The aim of the work is twofold. Firstly it is a more severe test of calculation methods as the second step change, at three boundary layer thicknesses downstream the first, occurs before the flow has fully adjusted to the rough surface. Secondly, the response of the boundary layer to the 'impulse' of surface roughness gives further indication of the structure of the turbulence. The measurements which have been made, include mean velocity, the three normal stress components and the shear stress, as well as the third order moments appearing in the turbulent kinetic energy equation. At the last measurement position, 55 boundary layer thicknesses from the roughness, the boundary layer has still not relaxed to the universal smooth wall structure. A preliminary calculation of the flow has been completed.

Gibbings of the University of Liverpool has continued his investigation of the influence of boundary layer trips upon separation (item 16.3). In the light of results of preliminary tests he has begun a detailed experimental investigation of the separation on a circular cylinder and on an aerofoil of the laminar, transitional and turbulent boundary layers.

Lewkowicz of the University of Liverpool reports progress on three items (16.5, 16.10 and 16.11). In item 16.5, an investigation of the effect of roughness on ship resistance and drag on marine surfaces, particular attention is being paid to (i) replication of marine surface roughness and its statistical appraisal (ie of its topography), (ii) correlation of the topographic parameters with the wall friction and other quantities representing the respective turbulent wall shear flow, (iii) destabilisation of the turbulent flow by the surface roughness. A reference 16.5a is given. For item 16.10 the work described in previous years has been extended to studying the recovery of a fully developed

turbulent pipe flow, in a pipe with and without irregular surface roughness, disturbed by a 'macro roughness' ring element. The mean and turbulent flow properties have been measured until full recovery and the effect of the pipe irregular background roughness on the recovery thus deduced. A Ref 16.10a is given. For item 16.11 Lewkowicz reports that the work is now concentrated on the effects of biologically acquired roughness elements on marine surfaces.

For item 16.7 Frössling of Chalmers University gives two new Refs 16.7a&b and reports that a final report including friction measurements and velocity and turbulence measurement on both smooth and rough walls will appear as a PhD thesis at the end of 1980.

For item 16.6 Tsen of CEAT Poitiers states that the work is now directed towards the measurement of the mean skin friction distributions about forward and rearward facing steps.

For item 16.9 Bertelrud of FFA has published a literature survey of surface roughness effects on the drag of subsonic aircraft[16.9a] and has developed a prediction method for these roughness effects[16.9b], and applied it to two aircraft[16.9c].

Finally in item 16.12 Krogstad, Fannelóp and Walderhaug of NTH Trondheim are developing a computer program to calculate the potential flow about ship hulls based upon the Hess and Smith method. Krogstad's three-dimensional boundary layer program is being extended to non developable surfaces and to include the effects of surface roughness.

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16.7a	R.I. Karlsson	Studies of skin friction in turbulent boundary layers on smooth and rough walls. Part 2 skin friction measurements in a turbulent flat plate boundary layer on a smooth wall. Chalmers University report to be published
16.7b	R.I. Karlsson	Turbulence structure in boundary layers on rough surfaces (in Swedish). Final report SSF Project 5518, The Swedish Ship Research Foundation, Göteborg (1980)
16.9a	A. Bertelrud	A literature survey of surface roughness effects on the drag of subsonic aircraft. FFA TN AU-1224 November 1978

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16.9c	A. Bertelrud	Roughness effects on fuel consumption for two commercial aircraft - McDonnell Douglas DC-9 and DC-10. FFA TN AU-1456 October 1979
16.10a	D.K. Das A.K. Lewkowicz	The recovery of a fully developed turbulent pipe flow behind a single blunt obstacle on a smooth and on an irregularly rough surface. Liverpool University Mech Eng Report FM/55/78
16.14a	G. Webel M. Schatzmann	The role of bed roughness in turbulent diffusion and dispersion. Proc 1 AHR Symposium on river engineering and its interaction with hydrological and hydraulic research, Belgrade (1980)
16.15a	J. Andreopoulos	The mean turbulent flow after a double charge of roughness. University of Karlsruhe Report SPB 80/E/149 (1979)
16.15b	J. Andreopoulos D.H. Wood	The response of a turbulent boundary layer to a short length of surface roughness. ICT AM Toronto (1980)

17 EXPERIMENTAL TECHNIQUES
Editor: P.D. Smith

This section contains those items which are mainly concerned with the development o new experimental techniques or the improvement of existing techniques which may be expected to be of use in the study of viscous shear flows. A major survey of experimental techniques has been published by Comte-Bellot (item 17.30, Ref 17.30g) who also gives a further six references.

Items 17.3, 17.4, 17.7, 17.12, 17.19, 17.26, 17.29, 17.31, 17.33, 17.36 and 17.42 have been finished and will be deleted next year. For items 17.29 and 17.33 final Refs are given. There is no progress to report for items 17.23, 17.25, 17.32, 17.38 and 17.45.

As in previous years comments on the remaining items will be divided into groups comprising those concerned with hot wire and hot film probes, laser anemometry and a group of miscellaneous techniques.

Hot wire and hot film probes

Gaviglio and Elna of IMST, Marseilles (item 17.34) are performing systematic investigations of the errors and their corresponding corrections arising from the use of hot wires in compressible flows. It has been shown that measurements of Reynolds stresses in high speed flows using yawed wires must be corrected for errors in the time lag, the influence of which is an order of magnitude greater than in subsonic flows.

Acrivlellis and Felsch of the University of Karlsruhe (item 17.39) have constructed a triple hot wire probe. It has proved difficult to keep the probe very small whilst maintaining the accuracy of the probe wire geometry. Measurements in highly turbulent flows are planned to improve the equipment. Six Refs are given, 17.39a-f.

Bartenwerfer of DFVLR, Berlin (item 17.40) is preparing a publication detailing his work on the use of hot wire anemometry in highly turbulent flows. He has numerically tested various formulae for obtaining the Reynolds stresses and mean velocity from the signals of an X-wire probe. This has shown that for very high turbulence intensity the conventional approximate formulae, which depend upon mathematical expansions to the velocity fluctuations, fail or lead to such large errors that only qualitative results are possible. This is so whether 'normal' linearised signals, 'squared' signals or special corrections by terms of higher order are used. For medium turbulence intensity (10-30%) it is possible to select the most appropriate formula for any particular case. Bartenwerfer has also investigated the problems of analysing the signals from probes with three or more wires and has designed some three wire probes that in principle permit an exact calculation of arbitrary products of the components of turbulent velocity. These can also be used with advantage in flows with lower turbulence intensity.

Alziary de Roquefort and Bonnet of CEAT, Poitiers have completed their study of the frequency response of a constant temperature hot-wire anemometer in supersonic flows by measurement of the phase response for several overheat ratios. The phase shift appears to be very important mainly below the cut-off frequency. They propose a test using a filtered sine wave signal to check amplitude and phase response. They now plan to calibrate a yawed wire and measure the turbulent shear stress in a supersonic wake. A Ref 17.43a is given.

Laser anemometry

Frössling of Chalmers University, Göteborg (item 17.15) has nearly completed a new design of the electronic system for his three component laser anemometer. Schodl of DFVLR, Cologne, gives a new Ref, 17.41a.

Miscellaneous techniques

Bertelrud of FFA, Stockholm has made what he terms a breakthrough in the use of McCrosky skin friction gauges (item 17.24). In order to use them for tests in flight (item 3.31) it was necessary to make a thorough analysis of the gauge characteristics. This together with calibration data obtained at NASA Ames has made it possible to deduce local skin friction over a wide range of conditions.

Frei of ETH, Zurich gives a new Ref, 17.37a, to his work on the direct measurement of skin friction in turbulent boundary layers with strong adverse pressure gradients.

Schöler of DFVLR, Gottingen, gives a new Ref, 17.44a, to his use of liquid crystals for heat transfer measurement.

Peube and Bousgarbies of LDF, Poitiers, have used their electrodeposition visualisation technique (item 17.22) to study the pattern of wall streamlines of the flow inside a square cross section annular cavity with two rotating adjacent walls. The experiments allowed the detection of a vortex in the vicinity of the angle formed by the two stationary walls.

Finally in item 14.26, Bousgarbies and Peube of LDF, Poitiers, have made an experimental study of chemically reacting turbulent mixing zones by combining their electrical conductivity technique with laser Doppler anemometry. Two Refs, 17.46a&b, are given and include distributions of mean conductivity and velocity and root mean square conductivity and velocity fluctuations. Values of the concentration velocity convariance have been obtained and the corresponding correlation function profiles are given.

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17.30d	G. Comte-Bellot J. Sabot I. Saleh	Detection of intermittent events maintaining Reynolds stress. Conference invitee Proc Dyn Flow Conference p 213-339 (1977)
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17.39c	M. Acrivlellis	A new evaluation method of hot wire anemometer measurements in low and highly turbulent flows. Proceedings, 8th IMEKO Congress Measurements for progress in Science and Technology, Moscow, May 1979
17.39d	M. Acrivlellis	An improved method of analysing hot wire signals of unsteady flows with low and high turbulence intensity. Proceedings, Dynamics Flow Conference, Baltimore, USA, September 1978
17.39e	M. Acrivlellis	Some remarks on the evaluation method. To be published in DISA-Information No.24
17.39f	M. Acrivlellis	Interpretation of triple hot wire probe signals. To be published
17.46a	R. Schodl	A laser two-focus (L2F) velocimeter for automatic flow vector measurements in the rotating components of turbo machines. In Measurement methods in rotating components of turbomachinery, proceedings of the Symposium, New Orleans, LA, 9-13 March 1980. Edited by B. Lakshminarayana and P. Runstadler, Jr, New York, ASME, p 139-147 ASME BK No.100130 (1980)
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No.	Author	Title, etc
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17.46b	J.M. Gatard J. Merault J.L. Bousgarbies	Transfert de masse entre deux jets plans parralleles de composition et de vitesse differentes. 4eme Congres Francais de Mecanique, Nancy 4-7 September 1979

18 EUROVISC REGISTER OF PROGRAMES AND SUBROUTINES (ERPS)

Editor: D.A. Humphreys

This new Eurovisc Annual Report section got off to a good start last year. There is one new publication reported, showing examples of the use of entry P79110. Apart from this, reference may be made to the 1979 edition of the Eurovisc report for full details.

The ERPS entries

Title Approximate two-dimensional turbulent velocity profile. — ERPS NAME P79010

Context Initial profile for boundary layer calculation. Curve-fit to experimental profile. Skin friction law.

Title SL (selbstadaptive Losung) - package for the self-adaptive solution of nonlinear systems of parabolic and elliptic equations. — ERPS NAME S79020

Context Elliptic equations. Finite difference equations. Parabolic equations. Self-adaptive error control.

Title Self-adaptive solution of the three-dimensional laminar incompressible boundary layer equations. — ERPS NAME P79030

Context Laminar boundary layers. Incompressible flow. Self-adaptive error control. See item 6.23.

Title Program for the calculation of incompressible three-dimensional turbulent boundary layers. — ERPS NAME P79040

Context Turbulent boundary layers. Incompressible flow. Turbulent energy methods. Finite difference equations. Three-dimensional flow.

Title Transport equation methods for calculating turbulent shear layers. — ERPS NAME P79050

Context Calculation methods. Boundary layers, wakes, mixing layers, three-dimensional flow. See also P79080.

Title Self-adaptive solution of the two-dimensional laminar hypersonic boundary layer equations with chemical nonequilibrium for air. — ERPS NAME P79060

Context Two-dimensional flow. Laminar boundary layers. Hypersonic flow. Nonequilibrium chemistry. See also S79020.

Title Monte-Carlo direct simulation computations of rarefied viscous flow fields. — ERPS NAME P79070

Context Rarefied viscous flow. Axisymmetric flow. Two-dimensional flow.

Title Higher order viscous-inviscid matching. — ERPS NAME P79080

Context Viscous flow over aerofoils. Internal flows. Viscous-inviscid interaction. Normal pressure gradients. See also P79050.

<u>Title</u> Time-dependent finite-volume programme for supersonic flow about blunt bodies. ERPS NAME P79090

<u>Context</u> Inviscid transonic/supersonic flow.

<u>Title</u> Conditional sampling of turbulence data. ERPS NAME P79100

<u>Context</u> Data analysis, turbulence statistics, conditional sampling.

<u>Title</u> Acoustic transfer function of a thin tube. ERPS NAME P79110

<u>Context</u> Pressure measuring systems. Acoustic transfer function.

<u>Method description</u> H. Bergh and H. Tijdeman have given in their report 'Theoretical and experimental results for the dynamic response of pressure measuring systems' (NLR-TR 238, 1965), an analytical solution of the linearised equations for the acoustic signal in a tube with consideration of the fluid viscosity. The proposed program (TUBEX) calculates the acoustic transfer function in a given frequency range for a single tube or for a connected series of N different tubes.

The report 'Bericht FO-1463: Messung von instationären Drücken mit einem einfachen Pitot' was published last year. It is a good example for a TUBEX-Application. Else no change.

<u>Programme characteristics</u> Fortran IV language for IBM 370 computer; card input and line printer (117 char/line) output; input - tube geometry (diameter, length), output - acoustic transfer function; typical run time 10 s. The program is self-contained and has been verified with examples in the cited report.

<u>Notes and limitations</u> Actual working medium = air. Program TUBEX is applicable to a 'shear wave number' $S < 21$, where $S = r(\omega/\gamma)^{\frac{1}{2}}$, r = tube radius, ω = circular frequency, γ = kinematic viscosity.

<u>Source</u> Listing of program TUBEX available on request from G. Mandanis, Eidg, Flugzeugwerk, Versuchs & Forschungsanlage, CH6032, Emmen, Switzerland.

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Title Transport equation methods for calculating turbulent shear layers. ERPS NAME P79050

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Title Higher order viscous-inviscid matching. ERPS NAME P79080

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LIST OF PROGRAMME ITEMS

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1.11	Statistical equations of compressible turbulent gases	IMST A. Favre
1.13	Flows of rotating fluids	LDF(P) J.L. Peube J. Pecheux J.L. Bourgartier
1.14	Viscous non-equilibrium nozzle flow	UBITF N.K. Mitra M. Fiebig
1.15	Study of flow between rotating bodies	LDF(P) Th. Alziary de Roquefort J.P. Bonnet
1.18	Numerical solution of the two-dimensional unsteady hydrodynamic equations	CEAT(P) L.F. Tsen M. Bouriot
1.19	Numerical solution of the Navier-Stokes equations for the flow between rotating cylinders	USM O. Booz H. Fasel
1.23	Laminar natural convection studies	UManMF J.A.D. Ackroyd
1.25	Simulated blood flow	UOsM E. Palm B. Johannessen
1.26	Rotating disc flows	UManMF J.A.D. Ackroyd
1.27	Studies of swirling flows	UManMF P.G. Bellamy-Knights
1.28	Study of implicit schemes for solving the compressible Navier-Stokes equations	ONERA H. Hollanders
1.30	Non-uniqueness of the flow along a semi-infinite flat plate at large Reynolds numbers	UGM A.I. van de Vooren
1.31	High order finite-difference solution of the Navier-Stokes equations	UPMT R. Peyret
1.32	Non-unique solutions of the Navier-Stokes equations for the von Karman swirling flows	TUT P.J. Zandbergen D. Dijkstra

No.	Title	
1.33	Unsteady horizontal jet in a stratified fluid	UPMT R. Peyret
1.34	A finite element method for Navier-Stokes equations	ONERA M. Morice
1.35	Numerical study of unsteady viscous incompressible flow past a circular cylinder with heat transfer	IMF(T) H. Ha Minh G. Martinez
1.36	Boundary conditions and a sufficient condition for instability at a fluid solid interface	UTA G. Kleinstein
1.37	Velocity and temperature field past continuously moving surfaces	UEMS B. Gampert
1.38	Solid sphere in an unsteady flow	CNRS A. Lasek
1.39	Multiphase flow	UKH F. Durst A.K. Rastogi B. Schönung
1.40	Turbulent separated flows	UKSFB A.K. Rastogi F. Durst
1.41	Generalised coordinates for flows	UKSFB F. Durst A.K. Rastogi
1.42	Three-dimensional numerical evaluation of heat loss through natural convection in a solar boiler	LDF(P) Th. Alziary de Roquefort
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2.4	Numerical studies of models of weakly non-linear instabilities of parallel and boundary layer flows.	USAG Th. Herbert
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2.8	Development of wave packets in a flat plate boundary layer	NPLMS M. Gaster
2.9	Development of method to predict transition in two-dimensional incompressible flow	TUDI J.L. van Ingen

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No.	Title	
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2.16	Numerical investigation of stability and transition in laminar boundary-layer flows	USM H. Fasel
2.17	Numerical investigation of stability and transition in steady and time-dependent plane Poisseuille flow	USM H. Bestek H. Fasel
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3.39	Wing-tip boundary layers	ULQMC H.P. Horton

No.	Title	
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3.41	Leading edge droops on swept wings	FFA M. Ingelman-Sundberg
3.42	Measurements in a two-dimensional incompressible turbulent boundary layer with nominally zero skin friction	TUB(HFI) H. Fernholz J.D. Vagt
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4.29	Unstable stratified boundary layers; application to the simulation of the atmospheric layer	ECL J. Mathieu J.P. Schon C. Rey
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4.33	Experimental analysis in order to bring additional information for computing methods	ECL E. Alcaraz G. Charnay J. Mathieu
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4.50	Turbulent shear flows with relaxation	UBITF K. Gersten
4.51	Gust structure	FFA M. Linde
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7.16	Compressible turbulent near wake study	CEAT(P) Th Alziary de Roquefort J.P. Bonnet
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7.25	Viscous-inviscid interaction near a trailing edge	NLR A.E.P. Veldman B. van den Berg

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7.26	Wake/boundary layer interaction	ULQMC H.P. Horton
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7.28	Viscous flow analysis in the trailing edge region of near-loaded airfoils	VFW/FOKKER P. Thiede G. Dargel
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8.23	Jet flow deceleration in injector-like channel configurations	SFAF R. Pozzorini J. Kamber
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8.29	Diffuser flow modelling	USaAME J.L. Livesey
8.30	The decay of turbulent velocity profiles	USaAME J.L. Livesey
8.31	Duct design for three-dimensional turbulent flow	USaAME J.L. Livesey J. Weir E.M. Laws

No.	Title	
8.32	Entrance effects on incompressible flow in conical diffusers	USaME J.L. Livesey J. Weir B. Lister
8.33	Flow in rotating channels	UKSS K.O. Felsch
8.34	Transonic flow in an air intake at large angle of attack	CEAT(P) R. Leblanc P. Ardonceau P. Thiebaut R. Goethals
8.35	Secondary flow losses in cascades of turbine blades	ULiME S.L. Dixon
8.36	Flow of highly viscous fluids between rotating discs	UKSS K.O. Felsch M. Piesche
8.37	Three-dimensional laminar cascade flow	DFVLR(TS) R. Grundman
8.38	Solution of the Navier-Stokes equations for the turbulent transonic flow through blade rows	USR H.H. Frühauf
8.39	Prediction of fully developed turbulent flow in rotating channels of rectangular cross section	UKSS K.O. Felsch R. Simon
8.40	Rapidly rotating gas flows	RIT/FFA F.H. Bark P.S. Meijer
9	SHOCK WAVE BOUNDARY-LAYER INTERACTIONS	
9.1	Experiments on normal shock wave/boundary layer interaction	NLR J.W. Kooi
9.2	Interaction of a normal shock wave with a two-dimensional turbulent boundary layer	RAE(B) W.G. Sawyer
9.4	Shock wave/turbulent boundary layer interaction in transonic and supersonic flows	ONERA J. Délery J.C. le Balleur
9.8	Normal shock wave/turbulent boundary layer interactions at small Mach numbers	CEAT(P) R. Leblanc V. Prouteau
9.9	Shock wave/boundary layer interactions with pressure gradient and injection	UCED L.C. Squire
9.11	Interaction of a vertical fin with a turbulent boundary layer	VKI B.E. Richards
9.13	Transonic shock/boundary layer interaction	DFVLR(ES) E. Stanewsky
9.14	Effect of boundary layer suction on oblique shock wave reflexion	CEAT(P) R. Leblanc J. Fournier R. Goethals

No.	Title	
9.16	Investigation of normal shock boundary layer interaction in transonic speed	VKI Chauvin R. van den Braembussche
9.17	The normal shock at a curved wall in turbulent boundary layer	UKSS J. Zierep R. Bohning
9.18	Shock structure of a moving shock close to a solid wall and growth of the beginning boundary layer	UKSS B. Schmidt
9.20	Three-dimensional shock wave boundary layer separation	USaAME D.F. Myring
9.22	Laser and hot wire anemometry in supersonic turbulent flows	CEAT(P) P. Ardonceau D. Lee R. Goethals
9.23	Shock/boundary layer interactions at transonic speeds	UCED L.C. Squire
9.24	Reynolds stress evolution in shock wave turbulence interaction	IMST J.F. Debieve J. Gaviglio
10	SEPARATION AND REATTACHMENT	
10.1	Development of a calculation method for laminar two-dimensional incompressible flow downstream of a separation point	TUDI J.L. van Ingen
10.3	Separation of turbulent boundary layers	ULQMC A.D. Young
10.7	Reattachment of the shear layer behind a step	ULICA P. Bradshaw
10.8	Experimental and theoretical study of the turbulent reattachment in supersonic flow	ONERA J. Délery J.C. le Balleur
10.11	Boat-tail flow separation	FFA J. Agrell
10.12	Axisymmetric wake recompression coefficient	FFA J. Agrell
10.21	Experimental study of the incompressible turbulent mixing and reattaching flow	ONERA J. Mirande J.C. le Balleur
10.23	Numerical investigation of regular laminar boundary layer separation	ULQMC H.P. Horton
10.24	Leading edge and fuselage vortex system formation and instability occurring on different delta wing configurations	DFVLR(ES) H. Bippes
10.27	Calculation of separated flow on airfoils	RAE(B) P.D. Smith

No.	Title	
10.30	Laminar boundary layer separation in a two-dimensional flow over a smooth step of small height	TUT D. Dijkstra
10.32	Numerical calculation of boundary layers with small separation bubbles	NLR A.E.P. Veldman
10.33	Numerical predictions and measurements in separated subsonic flows	IMF(T) H. Ha Minh P. Chassaing G. Martinez
10.34	Calculations of flows with recirculation	UKSFB W. Rodi
10.35	Axisymmetric turbulent separation bubbles	UCED E.P. Sutton
10.36	Two-dimensional, low-speed separation and reattachment	ULQMC H.P. Horton
10.37	Analysis of two-dimensional separated flow regions on the basis of boundary layer theory	VFW-Fokker GmbH P. Thiede G. Dargel
10.38	Turbulent separation through upstream injection (Formerly item 15.10)	THAAI E. Krause N.E.E. Hewedy
10.39	Calculation of two-dimensional flows based on strongly interactive viscous-inviscid methods, including separation, shock waves, trailing edge effects and wakes (Formerly item 9.21)	ONERA J.C. Le Balleur
10.40	Forces on control fins located in region of separation	FFA J. Agrell
11	FREE SHEAR LAYERS AND JETS	
11.2	An investigation of a two-dimensional jet in an external stream	ULQMC A.D. Young
11.3	Study of the mixing of two symmetrical and opposing jets in a hypersonic flow	CNRS G.B. Diep J.F. Devillers
11.7	Experimental and theoretical studies of jets and mixing layers	UManMF N.H. Johannesen
11.11	Turbulent mixing of jets	ONERA O. Leuchter
11.15	Calculation of turbulent boundary free shear layers	FFA D.A. Humphreys
11.18	Axisymmetric pipe jets: Air-Air or CO_2-Air	IMF(T) P. Chassaing H. Ha Minh H. Boisson
11.19	Experimental and theoretical investigation of swirling jets	UKSFB W. Rodi

No.	Title	
11.20	Experimental and theoretical study of jets in cross flow	UKSFB W. Rodi
11.21	Non-isothermal free jets	UBITF K. Gersten
12	HEAT TRANSFER	
12.3	Skin friction and heat transfer at supersonic speeds in the presence of pressure gradients	ULQMC H.P. Horton
12.8	Hypersonic rarefied flow over cones at angle of attack	DFVLR(ES) H. Legge G. Koppenwallner
12.10	Heat transfer from bodies with limited heat conductivity	UCFD N. Frössling
12.12	Laminar and turbulent heat transfer on surfaces at high angles to hypersonic flow	VKI B.E. Richards
12.14	Heat and mass transfer at nozzle wall near the sonic throat	DFVLR(AF) K. Kindler
12.15	Flow of humid air over cold surfaces	ULiME S.L. Dixon
12.16	Turbulent heat and mass transfer	UEMS M. Jischa
13	MASS TRANSFER AND BOUNDARY LAYER CONTROL	
13.3	Dynamical and thermal study of a turbulent flow in a tube with suction at the wall	IMST M. Eléna
13.6	Heat transfer rate measurements on film cooled surfaces	UOxEs D.L. Schultz
13.11	Very low velocity wall jet	CNRS A. Lasek
13.12	Turbulence and cavitation control	RIT M.T. Landahl
13.13	Film cooling applied to hot turbines	VKI B.E. Richards
13.14	Laminar boundary layers with suction or injection	UBITF K. Gersten
13.15	Influence of high polymer additives on laminar as well as turbulent fluid flow	UKH F. Durst R. Kleine A.K. Rastogi
13.16	Supercritical airfoil flow control by slot suction in the shock region	VFW P. Thiede
13.17	Laminar flow control for friction drag reductions of supercritical wings	VFW P. Thiede

14 PRESSURE FLUCTUATIONS, AERODYNAMIC NOISE GENERATION AND THE EFFECT OF FREE STREAM FLUCTUATIONS

No.	Title	
14.4	The wake behind and the forces on a vibrating cylinder at low Reynolds numbers	TUB(HFI) E. Berger R. Landl H.G. Lohmer
14.15	Influence of tunnel pressure fluctuations on transition in the subsonic and transonic regimes	NLR R. Ross
14.17	Aerodynamic noise associated with pressure	DFVLR(Be) T. Gikadi M. Bartenwerfer H.V. Fuchs W. Neise
14.18	Sound source location in turbulent jets	DFVLR(ES) F.R. Grosche
14.19	Generation of noise from an aerofoil located next to a random turbulent boundary	ECL G. Comte-Bellot M. Sunyach
14.20	Effects of free stream turbulence upon a boundary layer with pressure gradient	CERT R. Michel
14.21	Effect of free stream turbulence on turbulent shear layers	ULICA P. Bradshaw
14.22	Noise generation and sound transmission in free shear layers leaving nozzle walls and edges	DFVLR(Be) D. Bechert U. Michel E. Pfizenmaier
14.23	Wind tunnel study of the aerofoil buffeting caused by unsteady flow separation speeds	CEAT(P) J. Tensi L.F. Tsen
14.24	Ultrasonic investigations of water with drag reducing additives	TUDn L. Björnö
14.27	Jet noise - theoretical modelling and comparisons with measured data	USoSV C.L. Morfey
14.29	Rheological properties of very dilute aqueous detergent systems	TUDn L. Björnö
14.31	Experimental and theoretical investigation of the effects of free stream turbulence on flow field and heat transfer	UCFD N. Frössling B. Sundén L. Hanarp
14.32	Flow induced vibration in tube bank	USaAME M. Zdravkovich
14.33	Nonlinear sound propagation in real gases	USoSV C.L. Morfey
14.34	Noise generated by cold subsonic jets	ECL D. Jure

15 UNSTEADY FLOWS

No.	Title	
15.1	Boundary layers in unsteady flows	ULQMC A.D. Young
15.2	High-frequency finite-amplitude oscillations in compressible laminar boundary layers	UStM R.J. Gribben
15.3	Interaction of shock waves with the flow in the mixing zone of plane jets	THAAI G. Marenbach H. Zeller E. Krause
15.9	Vortex formation through shocks	THAAI E. Krause
15.10	Shock wave diffraction and reflexion through obstacles (Turbulent separation through upstream injection)	THAAI E. Krause N.I.I. Hewedy
15.11	Shock wave oscillations on airfoils	THAAI Th Franke E. Krause
15.14	Analysis of average and turbulent characteristics of an oscillatory boundary layer	CERT P. Michel J. Cousteix R. Houdeville
15.15	Turbulence produced by a periodic flow near the entrance of a pipe	LDF(P) J.L. Peube J. Peube
15.17	Experiments and theoretical calculations on viscous roll damping	UTNTH(DSH) O. Faltinsen
15.18	Measurements in two-dimensional unsteady incompressible turbulent boundary layers	TUB(HFI) H. Fernholz J.D. Vagt W. Reitebuch
15.19	Boundary layers along an oscillating airfoil	UBFM Ch Hirsch
15.20	Unsteady turbulent boundary layer separation	THZ M.O. Ehrensperger H. Thomann
15.21	The transition laminar - turbulent during the transient response of compressible pipe flow	THZ A. Lommel H. Thomann
15.22	Unsteady aerodynamics of aerofoils and helicopter rotorblades	IMF(M) Ch Maresca
15.23	Oscillatory turbulent boundary layers	TUDR I.G. Jonsson

16 EXCRESCENCES AND ROUGHNESS EFFECTS

No.	Title	
16.3	Influence of boundary-layer trips upon separation	ULiME J.C. Gibbings
16.5	Investigation of the effect of roughness on ship resistance using a pipe flow technique	ULiME A.K. Lewkowicz A.J. Musker
16.6	Velocity correlations and energy spectra in a turbulent boundary layer over a rough wall	CEAT(P) L.F. Tsen N.D. Vinh
16.7	Skin friction measurements on smooth and rough surfaces (especially ship hull roughness)	UCFD N. Frössling
16.9	Roughness effects on boundary layers of aircraft and wind tunnel models	FFA A. Bertelrud E.J. Totland
16.10	Interaction of a macro-roughness element with a micro-background roughness in turbulent shear flows	ULiME A.K. Lewkowicz
16.11	Turbulent shear flows on surfaces whose roughness comprises an irregular solid background and superimposed flexible elements	ULiME A.K. Lewkowicz
16.12	High Reynolds number viscous resistance on rough ship surfaces	UTNTH T.K. Fanneløp H. Walderhaug
16.13	The effect of roughness on three-dimensional turbulent boundary layers	UTNTH P.A. Krogstad
16.14	The role of bed roughness in turbulent diffusion and dispersion	UKSFB M. Schatzmann G. Webel
16.15	Double step change of surface roughness in a turbulent boundary layer	UKSFB J. Andreopoulos

17 EXPERIMENTAL TECHNIQUES

17.3	Comparative temperature measurements in a hypersonic turbulent boundary layer by means of a Maier probe and FFA's mass flow probe	FFA G. Hovstadius
17.4	Measurement of surface shear with a floating element transducer	UOxES R.E. Franklin
17.7	Measurement of turbulence and Reynolds stresses in compressible flow	ULiME J.C. Gibbings
17.12	Experimental techniques adapted for boundary layer investigations in a towing water basin	DFVLR(ES) P. Colak-Antić
17.15	Development of instruments and measurements methods for velocity and temperature fields	UCFD N. Frössling
17.16	Study of hot wire anemometer in highly turbulent flow	CNRS Sananes

No.	Title	
17.19	Development of a laser anemometer	ISB J. Kux
17.22	Visualisation of the wall streamline by an electro-chemical method	LDF(P) J.L. Peube
17.23	Flow velocity measurements using an electro-chemical method	LDF(P) J.L. Bousgarbies
17.24	Measurements of local skin friction	FFA A. Bertelrud
17.25	Measurement of directional errors of yaw-meters in a uniform shear flow	ULiME S.L. Dixon
17.26	Hypersonic boundary layer on axisymmetric bodies	UOxES D.L. Schultz
17.29	Hot wire data corrections in high turbulence intensity flows	UKM H. Schollmeyer
17.30	Hot-wire anemometry	ECL G. Comte-Bellot
17.31	Use of surface hot films to detect transition, separation and shock wave boundary layer interaction	NLR R. Ross
17.32	Investigation of the wake of a full scale ship by laser anemometry	ISB J. Kux
17.33	Local non-intrusive measurement of fluid dynamic properties using electron and laser beams	DFVLR(AF) K. Stursberg G. Schweiger M. Becker
17.34	New results about hot-wire anemometry	IMST J. Gaviglio M. Eléna
17.36	The measurement of fluctuating quantities in compressible turbulent flows	USaAME J.L. Livesey W.A. Kamal
17.37	Direct measurement of local skin friction in turbulent boundary layers with adverse pressure gradients	THZ D.H. Frei H. Thomann
17.38	Instrumentation error	USaAME J.L. Livesey B. Lister J. Weir
17.39	A new evaluation technique for hot wire measurements	UKSS M. Acrivellis K.O. Felsch
17.40	Hot wire and hot film probes	DFVLR(Be) M. Bartenwerfer
17.41	Laser two focus anemometry	DFVLR(AT) R. Schodl
17.42	Development of improved Laser-Doppler anemometers using counter signal processing	UKSFB W. Rodi

No.	Title	
17.43	Constant temperature anemometry in supersonic flows	CEAT(P) Th. Alziary de Roquefort J.P. Bonnet
17.44	Interference heating	DFVLR(ES) H. Schöler
17.45	Development of Laser-Doppler anemometers and their application in single and two phase flows	UKR F. Durst
17.46	Mass transfer in plane turbulent mixing layers	CEAT(P) J.L. Bousgarbie J.L. Peube
18	EUROVISC REGISTER OF PROGRAMS AND SUBROUTINES (ERPS)	
P79010	Approximate two-dimensional turbulent velocity profile	FFA D.A. Humphreys
S79020	SL (selbstadaptive Lösung) package for the self-adaptive solution of non linear systems of parabolic and elliptic equations	UKR W. Schönauer
P79030	Self-adaptive solution of the three-dimensional laminar incompressible boundary layer equations	UKR W. Schönauer
P79040	Programme for the calculation of incompressible three-dimensional turbulent boundary layers	NLR J.P.F. Lindhout
P79050	Transport equation methods for calculating turbulent shear layers	ULICA P. Bradshaw
P79060	Self-adaptive solution of the two-dimensional laminar hypersonic boundary layer equations with chemical non-equilibrium for air	UKR W. Schönauer
P79070	Monte-Carlo direct simulation computations of rarefied viscous flow fields	ULICA J.K. Harvey
P79080	Higher order viscous-inviscid matching	ULICA P. Bradshaw
P79090	Time-dependent finite-volume programs for supersonic flow about blunt bodies	FFA A.W. Rizzi
P79100	Conditional sampling of turbulence data	ULICA P. Bradshaw
P79110	Acoustic transfer function of a thin tube	SFAF G. Mandonis

Appendix

LIST OF ABBREVIATIONS AND ADDRESSES OF RESEARCH CENTRES

The items contributed by the research centres are also given in this list.

CEAT(P)	Centre d'Etudes Aérodynamiques et Thermiques de Poitiers (CEAT Poitiers) 43 Route de l'Aérodrome F-86000 Poitiers France (Items 1.18, 3.14, 7.16, 8.34, 9.8, 9.14, 9.22, 14.23, 16.6, 17.43, 17.46)	Telephone: (49) - 413939 (49) - 412640
CERT	Centre d'Etudes et de Recherches de Toulouse Départment d'Etudes et de Recherches en Aérothermodynamique 2 Avenue Edouard Belin F-31055 Toulouse France (Items 2.12, 3.36, 4.53, 5.8, 6.5, 15.14)	Telephone: (61) - 531188 Telex: 51647
CIT	Aerodynamics Division College of Aeronautics Cranfield Institute of Technology Cranfield Bedford, MK43 OAL England (Item 2.20)	Telephone: Bedford (0234) - 750111 Telex: 825072
CNRS	Laboratoire d'Aérothermique 4 Route des Gardes F-92190 Meudon France (Items 1.38, 2.11, 11.3, 13.11, 17.16)	Telephone: 6260750 Telex: 26034
DFVLR(AF)	Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt Abteilung Forschungsanlagen Linder Höhe D-5000 Köln 90 W. Germany (Items 2.3, 12.14, 17.33)	Telephone: (02203) 6011 Telex: 8874410
DFVLR(AT)	Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt Institut für Antriebstechnik Linder Höhe D-5000 Köln 90 W. Germany (Item 17.41)	Telephone: (02203) 6011 Telex: 8874410
DFVLR(Be)	Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt Abteilung Turbulenzforschung Muller-Breslau-Strasse 8 D-1000 Berlin 12 W. Germany (Items 4.13, 14.17, 14.22, 17.40)	Telephone: (030) 3133083 Telex: 184262 (via TU Berlin)

DFVLR(ES)	Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt Institut für Experimentelle Strömungsmechanik Bunsenstrasse 10 D-3400 Göttingen W. Germany (Items 3.34, 3.35, 4.1, 4.34, 8.15, 9.13, 10.24, 12.8, 14.18, 17.12, 17.44)	Telephone: (0551) 7091 Telex: 96839
DFVLR(TS)	Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt Institut für Theoretische Strömungsmechanik Bunsenstrasse 10 D-3400 Göttingen W. Germany (Items 2.10, 6.11, 6.21, 8.37)	Telephone: (0551) 7091 Telex: 96839
DOR	Dornier GmbH Postfach 1420 D-7990 Friedrichshafen W. Germany (Items 1.43, 6.27, 6.28)	Telephone: (07545) 82328 Telex: 0734372
ECL	Ecole Centrale de Lyon Laboratoire de Mécaniques des Fluides F-69130 Ecully France (Items 4.25, 4.26, 4.27, 4.29, 4.33, 5.18, 8.17, 14.19, 14.34, 17.30)	Telephone: (78) 332700
FFA	The Aeronautical Research Institute of Sweden P.O. Box 11021 S-161 11 Bromma Sweden (Items 3.23, 3.31, 3.40, 3.41, 4.51, 6.7, 6.17, 6.32, 8.40, 10.11, 10.12, 10.29, 10.40, 11.15, 16.9, 17.3, 17.24)	Telephone: (08) 26 28 40 Telex: S-10725
IMF(M)	Institut Mécanique des Fluides Université d'Aix-Marseille 1 Rue Honnorat F-13331 Marseille (3e) France (Item 15.22)	Telephone: (91) 622823
IMF(T)	Institut de Mecanique des Fluides 2 Rue Camichel F-31071 Toulouse France (Items 1.35, 4.45, 7.24, 10.33, 11.18)	Telephone: (61) 528648 Telex: 628686
IMST	Institut de Mécanique Statistique de la Turbulence 12 Avenue Général Leclerc F-13331 Marseille (3e) France (Items 1.11, 3.44, 4.10, 4.11, 4.43, 4.52 5.7, 9.24, 13.3, 17.34)	Telephone (91) 641650 641651

ISB	Institut für Schiffbau Lämmersieht 90 D-2000 Hamburg 33 W. Germany (Items 3.11, 3.46, 6.2, 17.19, 17.32)	Telephone: (040) 291881 Telex: 214732 (Via University Hamburg)
LDF(P)	Laboratoire de Dynamique des Fluides de l'Universitie de Poitiers 40 Avenue du Recteur Pineau F86022 Poitiers France (Items 1.13, 1.15, 1.42, 3.15, 4.23, 4.28, 4.41, 15.15, 17.22, 17.23)	Telephone: (49) 462633 Telex: None
MBB	MBB-UFE 122 Postfach 80 11 60 D-8000 München 80 W. Germany (Item 6.34)	Telephone: (089) 60004904 Telex: 5287-910 mbbd
NLR	Nationaal Lucht-en Ruimtevaart-laboratorium Anthony Fokkerweg 2 1059 CM AMSTERDAM The Netherlands (Items 3.8, 3.22, 6.9, 7.25, 9.1, 10.32, 14.15, 17.31)	Telephone: (020) 5113113 Telex: 11118
NPLMS	Division of Maritime Science National Physical Laboratory Teddington Middlesex TW11 OPG England (Item 2.8)	Telephone: London (01) 977 3222 Telex: 262344
NSP	Netherlands Ship Model Basin Haagsteeg 2 PO Box 28 6700AA Wageningen The Netherlands (Items 6.31, 6.35)	
ONERA	Office National d'Etudes et de Recherches Aerospatiales 29 Avenue de la Division Leclerc F-92320 Chatillon-sous-Bagneux France (Items 1.28, 1.34, 7.6, 9.4, 10.8, 10.21, 10.39, 11.11)	Telephone (1) 7852111 2535080
RAE(B)	Aerodynamics Department Royal Aircraft Establishment Bedford England (Items 6.3, 9.2, 10.27)	Telephone: Bedford (0234) 55241 Telex: 82117
RAE(F)	Aerodynamics Department Royal Aircraft Establishment Farnborough, Hants GU14 6TD England (Items 3.7, 3.45)	Telephone: Aldershot (0252) 24461 Telex: 85134
RIT	Royal Institute of Technology, KTH S-100 44 Stockholm Sweden (Items 8.40, 13.12)	Telephone: (08) 7877000 Telex: 10389

SFAF	Swiss Federal Aircraft Factory CH-6032 Emmen Switzerland (Item 8.23)	
SSPA	The Swedish State Experimental Shipbuilding Tank Box 24001 S-400 22 Goteborg Sweden (Items 3.12, 5.29, 6.29)	Telephone: (031) 200130 Telex: 20863
THAAI	Aerodynamisches Institut Rheinisch-Westfalische Technische Hochschule Aachen Templergraben 55 D-5100 Aachen W. Germany (Items 1.5, 4.44, 5.13, 6.10, 10.38, 15.3, 15.9, 15.11)	Telephone: (0241) 805410 Telex: 832704
THD	Technische Hochschule Darmstadt Fachgebiet Thermische Turbomaschinen und Anlagen Petersenstr. 30 D-6100 Darmstadt W. Germany (Item 8.25)	Telephone: (06151) 161 Telex: 0419579
THE	Department of Applied Physics Technische Hogeschool PO Box 513 Eindhoven The Netherlands (Items 4.9, 4.56)	Telephone: (040) 479111 Telex: 51163
THZ	Institut für Aerodynamik Eidgenössische Technische Hochschule Sonneggstr. 3 CH-8006 Zurich Switzerland (Items 2.30, 15.20, 15.21, 17.37)	Telephone (01) 326211
TUB(HFI)	Hermann-Fottinger-Institut für Strömungsmechanik Technische Universität Berlin Muller-Breslau, Strasse 8 D-1000 Berlin 12 W. Germany (Items 3.10, 3.42, 14.4, 15.18)	Telephone: (030) 3141 Telex: 184262
TUB(HRI)	Hermann-Rietschel-Institut für Heizungs-und Klimatechnik Technische Universität Berlin Marchstrasse 4 D-1000 Berlin 10 W. Germany (Item 4.32)	Telephone: (030) 3142618 Telex: 184262
TUB(T)	Institut für Thermodynamik Technische Universität Berlin Strasse des 17 Juni 135 D-1000 Berlin 12 W. Germany (Item 4.36)	Telephone: (030) 8381 Telex: 184262

UEMS	Universität Essen-Gesamthochschule Fachbereich 12 Maschinentechnik - Strömungslehre Unionstrasse 2 - Bergmann-Haus D-4300 Essen 1 W. Germany (Items 1.37, 5.27, 12.16)	Telephone: (0201) 1831 Telex: 8579091
UGM	University of Groningen Department of Mathematics PO Box 800 Groningen The Netherlands (Items 1.30, 2.29)	Telephone: (050) 119111
UKH	Institut für Hydromechanik Universität Karlsruhe Kaiserstrasse 12 D-7500 Karlsruhe 1 W. Germany (Items 1.39, 13.15)	Telephone: (0721) 6081 608-3897 Telex: (0)-782-6521 5621
UKM	Universität Kaiserslautern Maschinenwesen Pfaffenbergstrasse, Gebäude 14 D-6750 Kaiserslautern W. Germany (Item 17.29)	Telephone: (0631) 8542300 Telex: 04-5627
UKSS	Institut für Strömungslehre und Strömungsmaschinen Universität Karlsruhe Kaiserstrasse 12 D-7500 Karlsruhe W. Germany (Items 2.5, 3.5, 8.19, 8.20, 8.33, 8.36 8.39, 9.17, 9.18, 17.39)	Telephone: (0721) 6081 Telex: 7826521
UKR	Rechenzentrum der Universitat Kaiserstrasse 12 D-7500 Karlsruhe 1 W. Germany (Items 1.45, 6.23, 17.45)	Telephone: (0721) 6081 Telex: 7826521
UKSFB	Sonderforschungsbereich 80 Universitat Karlsruhe Kaiserstrasse 12 D-7500 Karlsruhe 1 W. Germany (Items 1.40, 1.41, 1.44, 4.46, 4.54, 4.55 5.32, 6.26, 10.34, 11.19, 11.20, 16.14, 16.15, 17.42)	Telephone: (0721) 608-3535 Telex: (0) 7826521 unid
ULICA	Imperial College Department of Aeronautics Prince Consort Road London SW7 2BY England (Items 2.26, 3.1, 3.3, 3.9, 3.37, 4.14, 4.19, 4.30, 4.47, 4.48, 5.24, 5.26, 8.21. 10.7, 14.21)	Telephone: London (01) 589-5111

TUDI	Department of Aeronautics Technical University Delft Kluyverweg 1 Delft The Netherlands (Items 2.9, 7.19, 10.1)	Telephone: (015) 133222
TUDn	Technical University of Denmark Department of Fluid Mechanics DK-2800 Lyngby Denmark (Items 14.24, 14.29)	Telephone: (02) 883088 Telex: 15048
TUDR	Technical University of Denmark Institute of Hydrodynamics and Hydraulic Engineering (ISVA) Building 115 DK-2800 Lyngby Denmark (Item 15.23)	Telephone: (02) 883088 Telex: 15048
TUL	Department of Transport Technology University of Technology Loughborough LE11 3TU England (Item 3.4)	Telephone: Loughborough (0509) 63171
TUT	Twente University of Technology Drienerlo PO Box 217 Enschede The Netherlands (Items 1.32, 10.30)	Telephone: 99111
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